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PRIMARY NATIVE SILVER ORES OF SOUTH LORRAINE AND COBALT, ONTARIO.

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INTRODUCTION.

AFTER a number of years of somewhat one-sided interest in the rich silver ores of Cobalt and vicinity based upon microscopic and chemical studies of ore specimens rather than field studies, the writer was enabled, in August, 1923, under the auspices of the Mining Corporation of Canada, to visit the region for the first time and to study in detail during a ten-day period the ores of the Frontier Mine at South Lorraine. Subsequently the numerous ore specimens from the Frontier Mine have been studied microscopically and compared with ores from a few other mines in the South Lorraine and Cobalt districts. The writer is permitted to publish the scientific results through the courtesy of the Mining Corporation.

I am particularly indebted to the Resident Geologist of the Mining Corporation, Warren H. Emens, for giving freely and generously of his time and his intimate knowledge of the local geology and for supplying many specimens of exceptional interest. Through the kindness of Major J. Mackintosh Bell I was enabled to study briefly portions of the neighboring Keeley Mine, but have refrained from commenting, except casually, upon the relations there observed because detailed studies of the ores are in progress by Major Bell and Mr. Ellis Thomson.

During several years of increasing familiarity with the region

and its ores, the writer's views of the genesis of the deposits have undergone important modifications and some of the views advanced in his earlier papers must now be modified or frankly abandoned. In a previous paper [1] the views which up to 1917 had been advanced concerning the origin of these ores were summarized. It seems unnecessary to repeat that summary here, its essence being a divergence of opinion as to whether the native silver was in the main a secondary (supergene) deposit from descending meteoric waters, or a primary (hypogene) deposit from ascending waters of deep-seated origin. Since the summary referred to was published, papers on the Cobalt ores have appeared by Whitehead,[2] Bastin,[3] and Whitman.[4] Whitehead regards the rich silver ores as late primary deposits from solutions coming probably from some unexposed deep-seated body of igneous rock. Whitman thinks that the ore minerals, including most of the native silver, were derived from the Nipissing diabase sill but came to their present position by a process of slow diffusion of mineral matter through relatively stagnant solutions and not as a result of vigorous circulatory movement of mineral-bearing solutions. Bastin, from a comparison of rich silver ores of Wickenburg, Arizona, with certain specimens from Cobalt, concluded that most of the silver at Cobalt was a late primary deposit. He presented experimental chemical evidence to show that nickel, cobalt and iron arsenides and antimonides are capable of precipitating metallic silver from silver bicarbonate solutions as well as from silver sulphate solutions.

In the present paper apparently conclusive evidence of the primary origin of nearly all of the native silver of the Frontier

[1] Edson S. Bastin, "Significant Mineralogical Relations in Silver Ores of Cobalt, Ontario," ECON. GEOL., XII., 1917, pp. 219–222.

[2] W. L. Whitehead, "The Veins of Cobalt, Ontario," ECON. GEOL., XV., 1920, pp. 103–135.

[3] E. S. Bastin, "Primary Native-Silver Ores near Wickenburg, Arizona, and their Bearing on the Genesis of the Silver Ores of Cobalt, Ontario," Bull. 735, U. S. Geological Survey, 1922, pp. 131–154.

[4] A. R. Whitman, "Genesis of the Ores of the Cobalt District," *Univ. of California Publications*, Vol. 13, 1922, pp. 254–307.

Mine at South Lorraine will be presented. It will be shown further that, however effective certain arsenides and antimonides may be in the laboratory as precipitants of metallic silver from silver solutions, the view that they functioned as precipitating agents in the deposition of any considerable part of the native silver at the Frontier Mine is clearly opposed to the microscopic evidence.

GENERAL GEOLOGIC RELATIONS AT SOUTH LORRAINE.

The South Lorraine District lies about 16 miles southeast of Cobalt, from which it may be reached by automobile road or by steamer on Lake Timiskaming. The principal operating mines are the Frontier Mine of the Mining Corporation and the Keeley Mine—adjacent properties.

The bed rocks at the mines are pre-Cambrian and include the following, named in inverse order of age:

	Geologic Age.
Nipissing diabase	Keweenawan.
Cobalt series (mainly conglomerates and graywacke)	Upper Huronian ?.
Feldspar porphyry Lamprophyre	Dikes cutting the Keewatin but not cutting the Nipissing diabase.
Flows, flow-breccias and tuffs of basaltic lava	Keewatin.

The Cobalt series, the prevailing wall-rock in the Cobalt district, is absent at the Frontier and Keeley mines though present near by.

The silver veins of the district are younger than and cut across all of the rocks listed above. They appear to have been formed, however, during pre-Cambrian times.

LARGER FEATURES OF THE VEINS OF THE FRONTIER MINE.

Veins Enumerated.—The principal veins of the Frontier Mine are the Woods, the Watson and the No. 1 veins. The No. 1 vein may be regarded as a branch of the Watson. These veins are of general northerly and southerly trend and are either vertical or very steeply inclined. The Woods vein has to date been

the most productive vein of the Frontier Mine and is also extensively developed in the Keeley workings lying farther south.

Widths.—Individual veins in the Frontier Mine are commonly a few inches in width—rarely over 10 inches, but several adjacent sub-parallel veins of these widths may occur. The walls of the veins are commonly sharp but in places are vague with very gradual transitions from vein material to wall-rock. Both types of contacts may be found within a few inches of each other along a vein wall.

Vugs.—In places vugs are common and occupy a large part of the space between the vein walls. In the Wood's vein a vug 1 by 2 by 3 feet was noted. In the Watson vein the vugs are apt to be angular and the wall-rock bordering them is commonly much shattered, with vein material filling the fractures. Such vuggy portions of the veins probably resulted from the partial filling of open fissures.

Elsewhere the veins for considerable distances may be essentially free from vugs.

Inclusions.—In several widely separated parts of the Frontier Mine the veins are crowded with inclusions that appear to be fragments of altered wall-rock. At one place in the Watson vein fully half of the vein consists of such inclusions in a calcite-rich matrix—metallic minerals being absent here. Plate I., *A*, shows its appearance. The walls here are Keewatin basalt and the fragments are either identical with or closely similar to the wall-rock in color and general appearance. They may be angular or somewhat rounded and their borders either sharp or vague. In places they are so extraordinarily numerous and closely crowded as to suggest that they are remnants left in a gradual replacement of a zone of shattered wall-rock by calcitic vein material rather than fragments of wall-rock caught up in the vein solutions. The replacement hypothesis receives some support from vein structures noted in No. 1 vein where it cuts Nipissing diabase. There a vein of white calcite 4 inches wide contains somewhat wandering bands of what appears to be altered wall-rock paralleling in a general way the walls of the vein but lying

within the white vein calcite. The width of these bands is irregular and their outlines ragged as shown in Plate I., *B*. Unfortunately microscopic study fails to prove or disprove that the bands are altered diabase. In one slide there was a suggestion of diabase texture but the component minerals are dominantly quartz and chlorite.

In other parts of the veins similar apparent replacement remnants of wall-rocks are enclosed by cobaltite and calcite.

Influence of Fracturing on Mineralization.—The vein fractures are in general strong and persistent and little deflected by changes in wall-rock. It is somewhat surprising to note that highly brecciated portions of the fracture zones were not in general as highly mineralized as other portions characterized by a few simple sub-parallel fractures. Presumably the explanation is that in brecciation more chlorite and gouge were developed and that these relatively impervious materials tended to block free access of later mineralizing solutions.

Blocking of Mineralization by Faults and Joints.—Near the No. 1 shaft on the 65-foot level a small vein, probably a branch from No. 1 vein, was observed to terminate at a fault in the manner sketched in Fig. 1, *A*. The vein terminated in T or mushroom fashion against the fault zone, the vein minerals showing no evidence of fracturing and no fragments of vein material occurring in the fault. It seems evident that the fault was present prior to mineralization and that mineralizing solutions circulating along the vein fracture were blocked by the fault and spread out in both directions along its border. Close to the shaft on this level, No. 1 vein, 4 inches wide, abuts against the same fault. It is deflected in one direction instead of in T fashion, as shown in Fig. 1, *B*, and within a few inches tapers out. The vein material shows no indication of fracturing and no ore fragments occur in the adjacent fault material.

Variability along Veins.—Great variability in kind and degree of mineralization within short distances along the veins is characteristic. The extreme instance of abrupt variation was noted in the Watson vein, where at one place a 3-inch vein of quartz,

calcite, and sparse cobaltite gives way within one inch along its trend to barren rock. No cross fractures were visible which could control this abrupt change. In the Wood's stope, about 80 feet above the third level, the vein, where rich, is a fractured zone about 5 feet wide traversed by two veins each 8 inches wide, mainly composed of metallic minerals. Within 30 feet along its trend in the same stope the "vein" changes to a brecciated zone 5 feet wide barren of *any* mineralization.

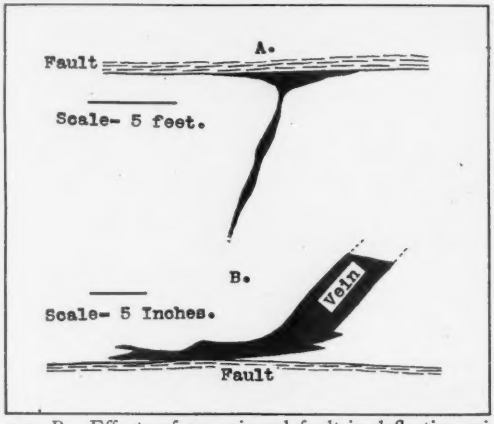
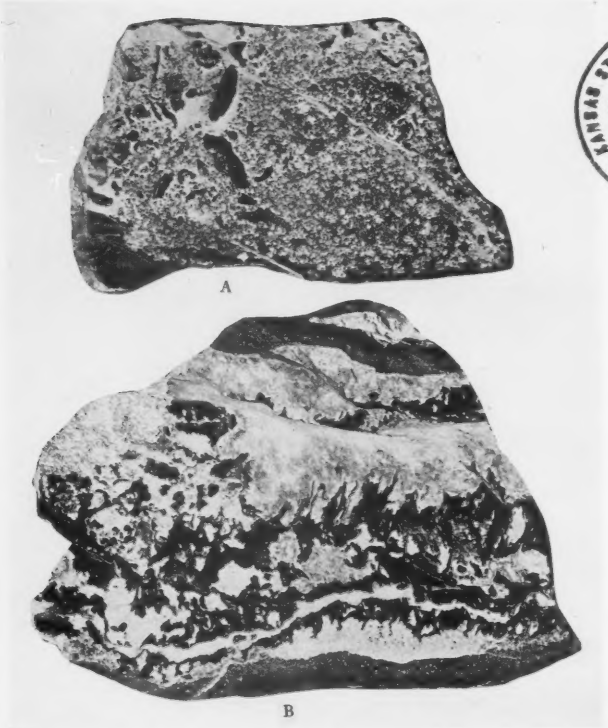


FIG. 1, *A* AND *B*. Effects of pre-mineral fault in deflecting mineralizing solutions. Sixty-five foot level, Frontier Mine.

Typical Rich Vein Exposure.—The appearance of a vein in one of its richest portions is typified by the Wood's vein in the Wood's stope, 80–90 feet above the third level. A fractured zone in Keewatin greenstone, averaging about 5 feet wide, is traversed here by two nearly parallel sharp-walled veins 8 to 10 inches wide and composed mainly of metallic minerals. The metallics are arsenides of iron, cobalt, and nickel, with, in places, native silver. In places the arsenides are arranged in rosette-like forms as shown in Fig. 2, the base of the rosettes always, so far as noted, being toward the foot-wall of the vein. In a few places in this stope vugs, a few inches across, occur within the metallic minerals of these veins. The walls of these vugs are commonly



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A

B

A. Full width of Watson vein, 4th level, Frontier Mine. Vein crowded with what appear to be fragments of wall-rock partially replaced by vein calcite. About one-half natural size.

B. Full width of vein No. 1, Frontier Mine, in diabase. Dark median portions appear to be replacement remnants of diabase bordered by vein calcite. About one-half natural size.

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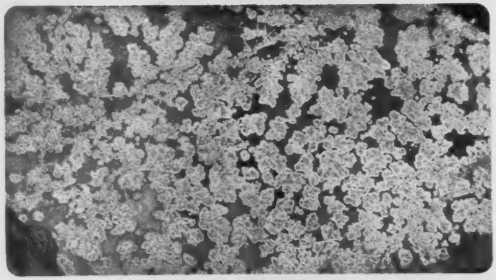
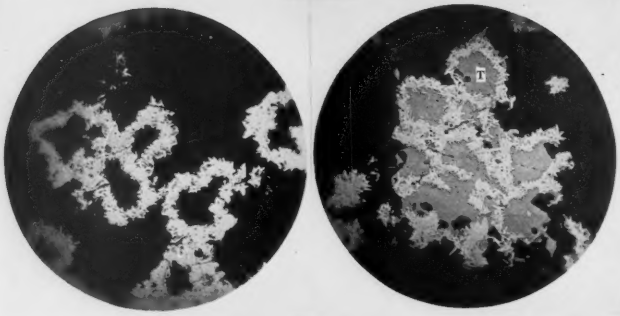


A



B C

A. Tubercle (or birds' eye) texture in rich silver ore from Townsite Mine, Cobalt. Three-fourths natural size.

B. Tubercle-like growths of arsenopyrite in calcite (black). Frontier Mine, South Lorraine.

C. Tubercle-like growths of arsenopyrite enclosing tetrahedrite (*T*); both enclosed in calcite. Frontier Mine, third level.

argentite and calcite in crystals which interlock with each other and at their base interlock with the arsenides.

Post-mineral Faulting along Veins.—After mineralization, faulting took place along the Wood's vein, as is clearly shown at several localities. In the Wood's stope, about 80 feet above the third level, a zone of irregular shattering 6 feet wide follows one side of the vein. At another place a similar shattered zone was 3½ feet wide.

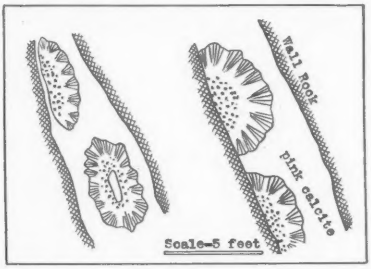


FIG. 2. Rosette-like distribution of metallic minerals in rich vein in Wood's Stope, above third level, Frontier Mine. The radiating crystals are arsenopyrite. Black dots near bases of rosettes represent niccolite.

GROUND-WATER LEVEL.

The ground-water level prior to mining, at the Frontier Mine, appears to have stood comparatively close to the surface. Its position may be inferred from the height at which water stood in the shafts during a period of idleness prior to the taking over of the mine by the present operators. According to Mr. James Harkness, former mine superintendent, water rose during that period to within 30 feet of the collar of No. 1 shaft, and, in the spring and fall, to within 20 feet of the collar of No. 2 shaft. All the workings examined by the writer were therefore well below the original ground-water level.

OXIDATION.

The highest accessible workings were the 65-foot level on No. 1 vein, connecting with shaft No. 1. This level is well below the original ground-water level as it existed prior to the

openings of the mine. Limonite and malachite, products of oxidation, were noted on this level, but they were in small quantities and were associated with remnants of unaltered chalcopyrite and abundant calcite. They might have developed during especially dry seasons of unusually low ground water level. Oxidation on this level of the mine is not general or thorough. On the 150-foot level and all deeper levels no oxidation was seen.

This situation contrasts markedly with that in the southern part of the adjacent Keeley Mine, where notable oxidation extends to at least the 560-foot level.[5]

Oxidized minerals observed are noted on page 110.

MINE WATERS.

Mine waters are uniformly cool, clear, and tasteless. Waters dripping through the vein were tested with litmus paper and with methyl orange solution at many places and were everywhere found to be neutral. These tests included waters from vugs carrying argentite and wire silver in the Wood's stope, 80 feet above the third level.

The following minerals have been recognized in the ores of the Frontier and Keeley mines at South Lorraine:

Primary Minerals:

Calcite (usually pink and slightly ferruginous. The dominant gangue).
Quartz.
Arsenopyrite (FeAsS) } usually the dominant metallics.
Cobaltite (CoAsS)[5a] }
Löllingite ($FeAs_2$) }
or Safflorite ($CoAs_2$) }
or both (see below) } common.
Niccolite (NiAs) }
Native Silver }

[5] J. Mackintosh Bell, "Deep-Seated Oxidation and Secondary Enrichment at the Keeley Silver Mine," Economic Geology, Vol. XVIII., 1923, pp. 684–694.

[5a] Cobaltite is identified by its pink tint, failure to react with any of the Davy-Farnham reagents, and its isometric crystallization as shown by its form and its behavior in polarized reflected light.

Smaltite ($CoAs_2$)
Breithauptite (NiSb).
Chalcopyrite ($CuFeS_2$).
Bornite ($3Cu_2S \cdot Fe_2S_3$).
(Keeley Mine).
Tetrahedrite ($4Cu_2S \cdot Sb_2S_3$).
Pyrite (FeS_2).
Pyrrhotite (near FeS).
(in Galena ores).
Galena (PbS).
Argentite (Ag_2S).
Proustite ($3Ag_2S \cdot As_2S_3$).
Sphalerite (ZnS).
Native Bismuth.

Although the gray metallics of the South Lorraine veins locally go under the name of "Smaltite," most of what has been so termed is an intimate mixture of cobaltite with arsenopyrite, löllingite or safflorite, one or all. Undoubted smaltite was noted in only one specimen. The commonest gray metallic in most of the ore is negative to all of the reagents used in the Davy-Farnham microchemical tests. It tends to develop prismatic forms, as well shown in Plate V., *B*, and is apparently orthorhombic. Examination by polarized reflected light shows that it is not isometric. Upon these criteria it would be identified as löllingite, but tests with impure material and analyses of large composite samples of rich ore made by the Mining Corporation indicate that cobalt is probably more abundant than iron in this mineral. Pure pieces large enough for certain determination were not obtainable. It is probable that the mineral is intermediate between löllingite ($FeAs_2$) and safflorite ($CoAs_2$). An isometric mineral, white in reflected light and unaffected by any of the Davy-Farnham reagents, does not correspond to any mineral listed by Davy and Farnham and was not identified. It is abundant in some specimens.

Secondary Minerals:

Some wire and plate silver.
Chalcocite (Cu_2S).
(Keeley Mine).
Mimetite (Lead Arsenate).
Lead Oxides.
Limonite.
Erythrite (Cobalt Bloom—$Co_3As_2O_8 + 8H_2O$).
Annabergite (Nickel Bloom—$Ni_3As_2O_8 + 8H_2O$).

WALL-ROCK ALTERATIONS.

Wall-rock alterations adjacent to the veins of the Frontier Mine, although observed, are not very conspicuous and do not extend for long distances from the veins.

In the Wood's stope, above the third level, the veins are sharp-walled against Keewatin greenstone. In the walls are scattered grains of arsenopyrite, niccolite and cobaltite, and effervescence with dilute hydrochloric acid shows the abundant development of calcite.

Two samples were collected from the third level especially to show the character of the alterations where the wall-rock was Nipissing diabase. The vein was 4 inches wide and largely pink calcite. For ¾ to 1 inch bordering the vein the diabase is slightly darker than normal and carries scattered minute crystals of cobaltite. A specimen 5 inches from the vein possesses a typical diabase texture (ophitic) and consists of augite largely altered to epidote, plagioclase largely altered to sericite and calcite, minor amounts of biotite partly altered to chlorite, and titaniferous magnetite partly altered to leucoxene. Some quartz occurs in an interstitial position and was the last mineral to crystallize, except that in places it is delicately (graphically) intergrown with feldspar. In the specimen from immediately adjacent to the vein the diabasic texture is still recognizable, but augite, epidote and biotite have been completely altered to chlorite. Sericite has largely given way to calcite and a few minute veinlets of the latter mineral traverse the rock.

It is uncertain whether the development of chlorite, epidote and sericite was accomplished by the mineralizing solutions. The carbonate radical was, however, certainly introduced in abundance during mineralization as were the nickel, cobalt and arsenic.

ORE TEXTURES AND THEIR MEANING.

The microscopic study of a large number of polished specimens of typical ores from the Frontier Mine show that certain textures are characteristic and throw light upon the genesis of the ores.

Tubercle Texture.—Many of the ores not only of South Lorraine but of Cobalt present in polished surface the appearance shown in Plate II., *A*. Among local mining men this is sometimes termed "bird's-eye" texture, but this name is of doubtful descriptive value when the third dimension in the ore is considered. If in such ore the calcite is dissolved in acid, the metallic minerals are found to form a coherent mass made up of short tubercles that coalesce at their base with other tubercles—no one being detached from its fellows. In higher magnification the tubercle texture as exhibited on a polished surface is shown in Plate II., *B* and *C*. These forms seem to imply deposition beginning at certain centers and progressing outward in various directions in irregular fashion through the formation of new tubercle-like branches.

There is evidence that many, if not most, of the tubercles in their early stages of growth were hollow and composed mainly of gray metallic minerals, notably arsenopyrite, löllingite, or safflorite, cobaltite, and smaltite, and that later calcite, niccolite, breithauptite, tetrahedrite, and native silver crystallized both within and around them. In Plate II., *C*, tetrahedrite (T) and calcite are shown both within and outside of tubercles of arsenopyrite. In Plate III., *A*, calcite and quartz within a tubercle are shown to be continuous with calcite and quartz outside. In Plate III., *B* and *C*, native silver (S) within tubercles is seen continuous with that outside.

Silver-Calcite Veinlets and Nests.—In the rich ore from all parts of the mine much of the native silver occurs in veinlets pre-

dominantly silver and calcite that traverse cobaltite, arsenopyrite, löllingite or safflorite, and rare smaltite. Typical veinlets of this sort are shown in Plates III., *D*, and IV., *A*, and in Fig. 3.

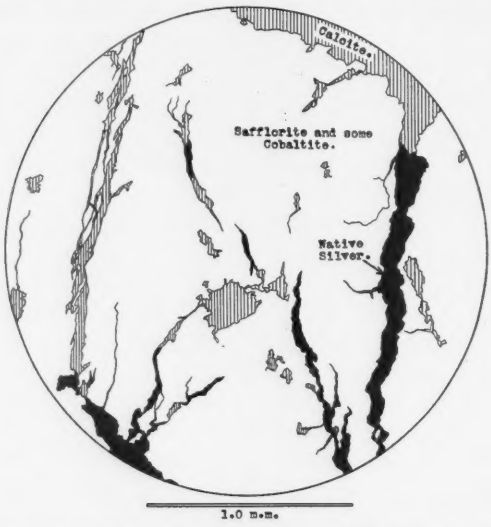
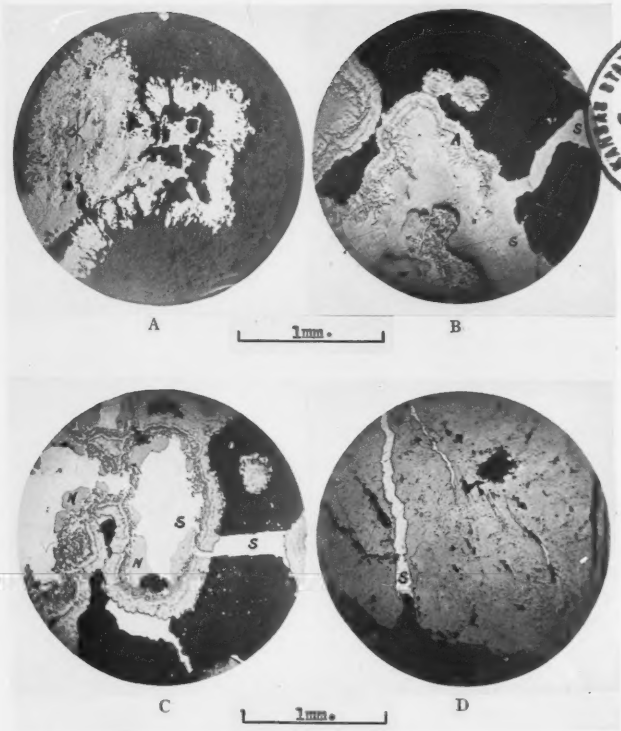


FIG. 3. Hybrid veinlets of Native Silver and Calcite traversing Safflorite?. Frontier Mine. Camera lucida drawing.

Other minerals occurring locally and in small amounts in these veinlets are niccolite, breithauptite, chalcopyrite, tetrahedrite, and sphalerite. (See Fig. 5.)

From the vein-like form of these associations of silver, calcite and minor components we must infer that they are somewhat younger than the materials that they traverse. The question then is *how much* younger are they? Two relationships afford an answer to this question: First, not uncommonly these veinlets pass gradually into irregular intergrowths of the silver, calcite, etc., with the iron and cobalt arsenides, as shown in Plate IV., *B*, and Fig. 4. Second, the veinlets are closely associated with and in places continuous with "nests" of silver or of silver and calcite of the sort shown in Plate IV., *C*, and, less



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A. Calcite and quartz (dark gray) within tubercle continuous with that outside. Frontier Mine, South Lorraine.

B. Native silver (*S*) within tubercles continuous with that outside. Black is calcite. *A* = arsenides. Townsite Mine, Cobalt.

C. Another part of same specimen shown in *B*. Native silver (*S*) within tubercle continuous with that outside. *N* = niccolite. Black is calcite.

D. Hybrid veinlets of silver (*S*) and calcite (black) traversing arsenides. Frontier Mine, South Lorraine.

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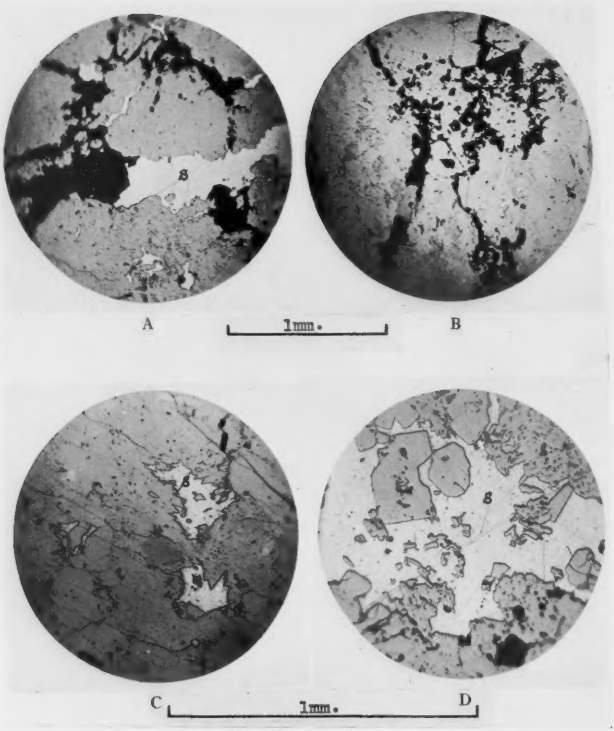
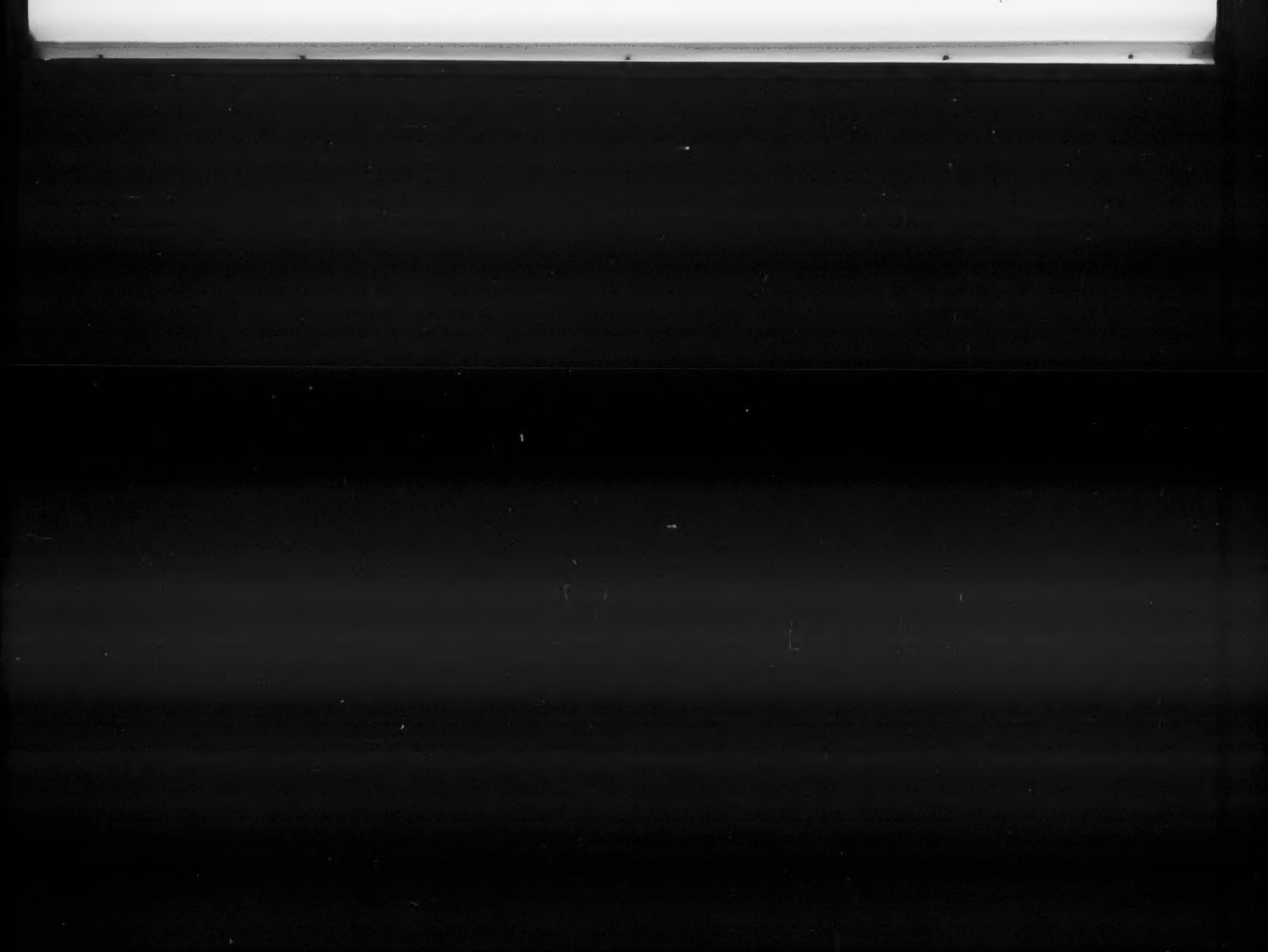


A. Hybrid veinlets of silver (*S*) and calcite (black) traversing arsenides. Frontier Mine, South Lorraine.

B. Calcite veinlets (black) in arsenides grading into irregular, contemporary intergrowths of calcite and arsenides. Frontier Mine.

C. Nests of native silver (*S*) in safflorite(?). Note that the latter shows its characteristic crystal faces against the silver. Frontier Mine.

D. Cobaltite and safflorite(?) showing crystal faces against native silver (*S*). Frontier Mine.



perfectly, in the lower part of Plate IV., *A*. Near these "nests," and near the veinlets as well, inclusions of silver and calcite in the arsenides are in places abundant. These relations show that deposition of silver and calcite began before deposition of iron and cobalt arsenides was completed and indicate that the veinlets are *not much younger* than the minerals they traverse.

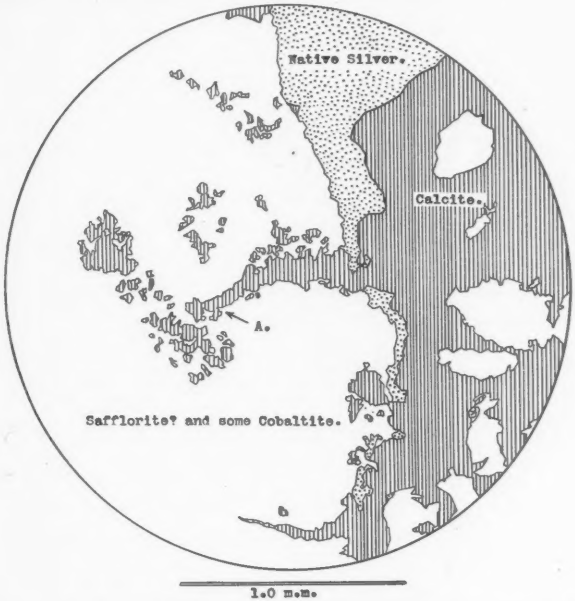


FIG. 4. Small branch from Calcite-Silver veinlet passing, near *A*, into an irregular intergrowth of Safflorite? and Calcite. Frontier Mine. Camera lucida drawing.

A second problem is: By what method were these veinlets deposited? In the writer's earlier papers [6] he interpreted them as replacement veinlets on the basis of their irregular forms and the

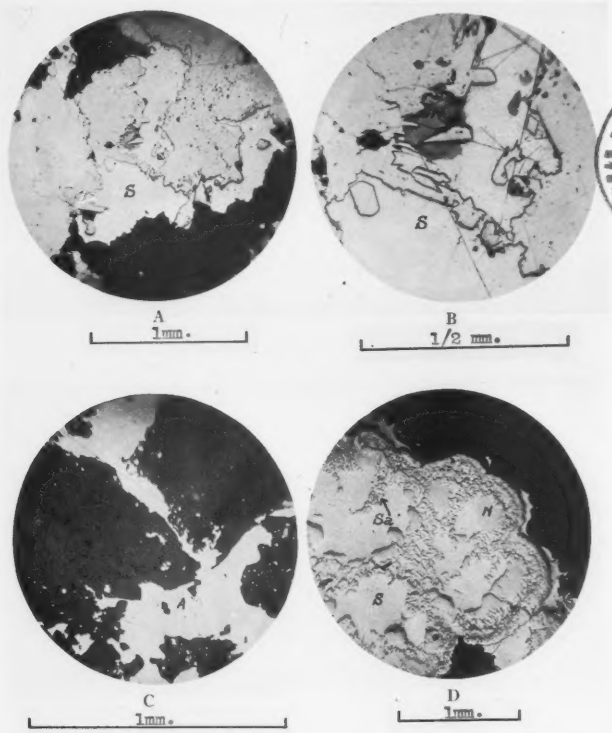
[6] E. S. Bastin, "Primary Native-Silver Ores near Wickenburg, Arizona, and their Bearing on the Genesis of the Silver Ores of Cobalt, Ontario," Bull. 735, U. S. Geol. Surv., 1922, pp. 131–154.

failure of opposite walls to match in the fashion characteristic of ordinary ruptures. Features which will next be described indicate that the veinlets are neither replacement veinlets nor fillings of ruptures of the *ordinary* sort, but that their formation demands a new explanation.

Study of the veinlets under high magnification shows that the minerals usually forming their walls (arsenopyrite, löllingite or safflorite, and cobaltite) *invariably show their own characteristic crystal faces.* This feature is clearly shown in Plate IV., *D,* and Plates V., *A* and *B.* Plate V., *B,* is an enlargement of a portion of V., *A.* Plate IV., *C,* shows the same feature in connection with the "nests" of silver. Plate V., *C,* shows silver veinlets in calcite. At *A* in this plate the crystalline outlines of the calcite against the silver are clearly shown, and higher power examination of the contacts that appear more ragged *invariably* shows the calcite with smaller crystal faces against silver.

It is axiomatic that if silver and calcite had replaced the iron and cobalt arsenides the crystal outlines of these minerals would have been at least partially destroyed. Similarly if, in the field shown in Plate V., *C,* silver had replaced calcite, the crystal outlines of the latter would have been destroyed. It would be incautious to assert, on the basis of the South Lorraine ores and scattered specimens from Cobalt mines, that native silver is nowhere in the district a replacement of other minerals, but in the specimens studied by the writer evidences of such replacement are wholly lacking.

A third problem is the source of the solutions from which the material of the veinlets was deposited. If, as already shown, only a brief interval elapsed between the deposition of the minerals of the vein walls and those of the vein itself, we should expect to find that both were deposited by solutions coming from a common source, *i.e.,* by primary or hypogene solutions. This supposition is confirmed by the mineral composition of some of the veinlets. With their dominant components, silver and calcite, there are irregularly intergrown in places small amounts of niccolite, breithauptite, chalcopyrite, tetrahedrite and sphalerite, as



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A. Safflorite(?) (gray) showing perfect crystal faces in contact with native silver (*S*). Black is calcite. Frontier Mine.

B. Part of the same field shown in *A* under higher magnification. *S* is silver. *N* is niccolite.

C. Silver veinlets (white) in calcite (black). Trehewey Mine, Cobalt. Note crystal faces of calcite against silver near *A*.

D. Contemporary intergrowths of native silver (*S*) with safflorite(?) (*Sa*) and niccolite (*N*). Townsite Mine, Cobalt.

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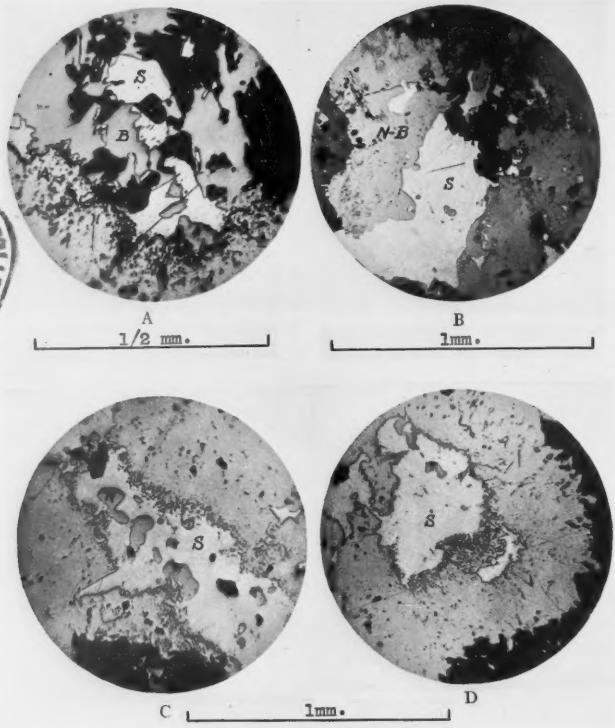
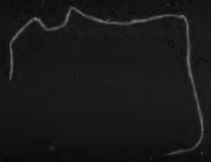


A. Breithauptite (*B*) showing crystal faces against native silver (*S*). Note inclusions of silver and calcite in safflorite, as at *A*. Black is calcite. Frontier Mine.

B. Niccolite and breithauptite (*N–B*), showing crystal faces against silver (*S*). Note also the crystal faces of calcite (black) against silver. Trehewey Mine, Cobalt.

C. Niccolite (*N*) with crystal faces against native silver (*S*). Kerr Lake Mine, Cobalt.

D. Native silver areas (*S*) within safflorite(?). Bordering the larger silver areas are abundant small inclusions of silver in safflorite. Black is calcite.



shown in Fig. 5. Such a mineral association is unknown and extremely unlikely to occur as a secondary deposit from descending meteoric waters. Furthermore, all these sulphides and arsenides in other situations in the ores are clearly primary minerals. The silver-calcite veinlets are interpreted, therefore, as late primary.

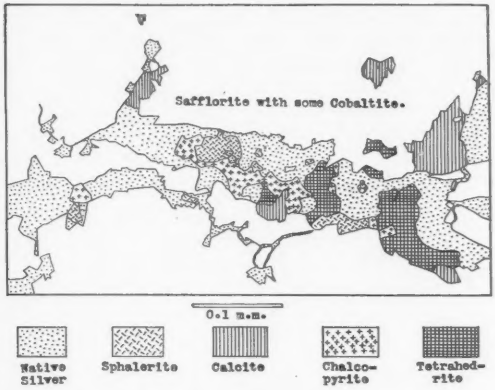


FIG. 5. Irregular veinlet of Native Silver, Calcite, Sphalerite, Chalcopyrite, and Tetrahedrite traversing Safflorite? with some Cobaltite. Frontier Mine. Camera lucida drawing.

If the silver-calcite veinlets were not formed by replacement, the only alternative is that they are fillings of ruptures, and this is the explanation adopted. They differ from the usual sort of rupture fillings, however, in that crystallization of the minerals of the walls continued during rupturing. It appears that as the crystallization of arsenopyrite, löllingite or safflorite, and cobaltite approached completion, but was still in progress, rupturing of the masses of growing crystals took place, and that in the remaining open spaces silver, calcite and their minor associates were deposited. The cause of the rupturing is uncertain.

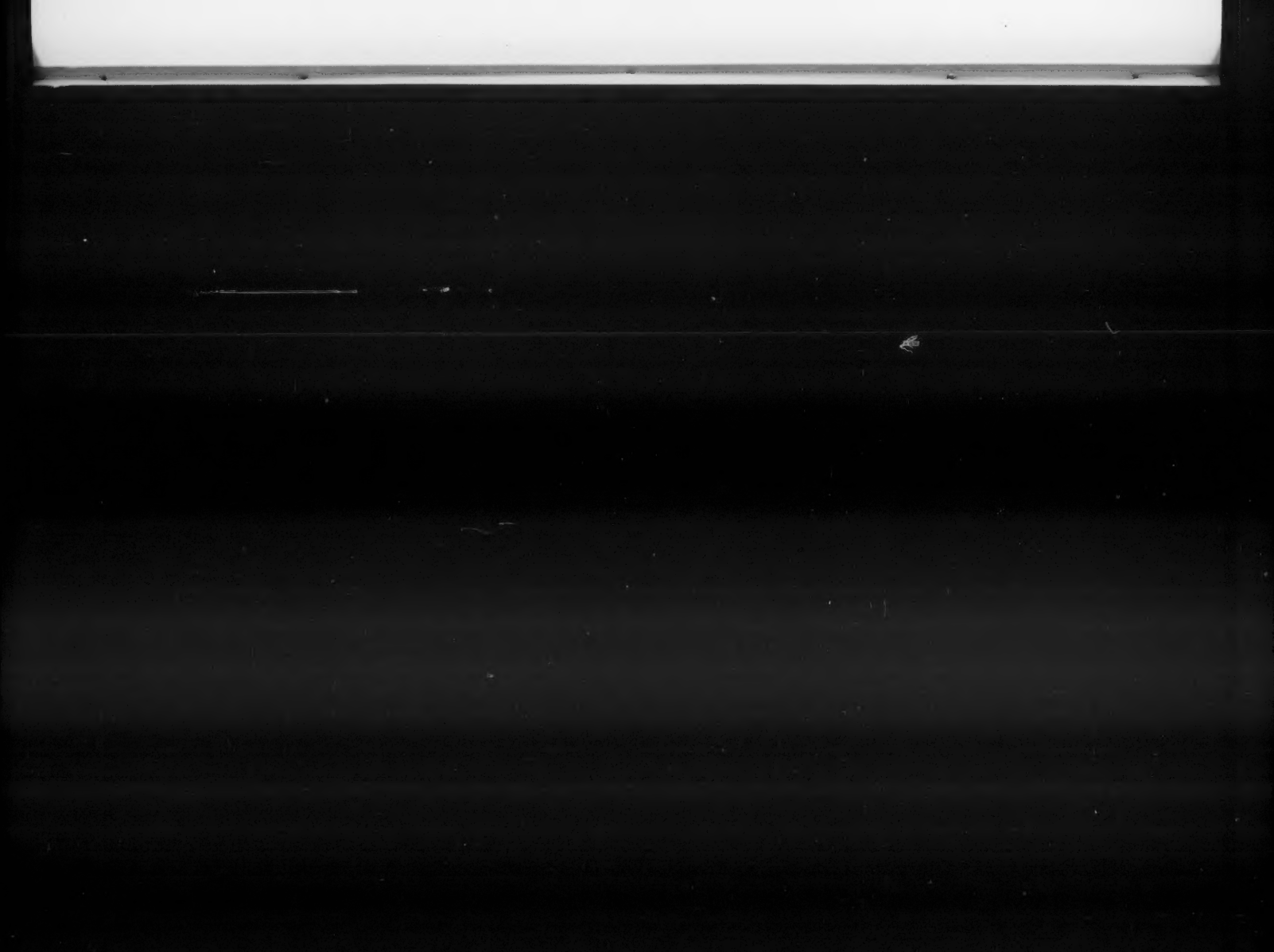
Intergrowths of Silver and Safflorite(?) in Townsite Mine, Cobalt.—In a specimen of rich ore from the Townsite Mine

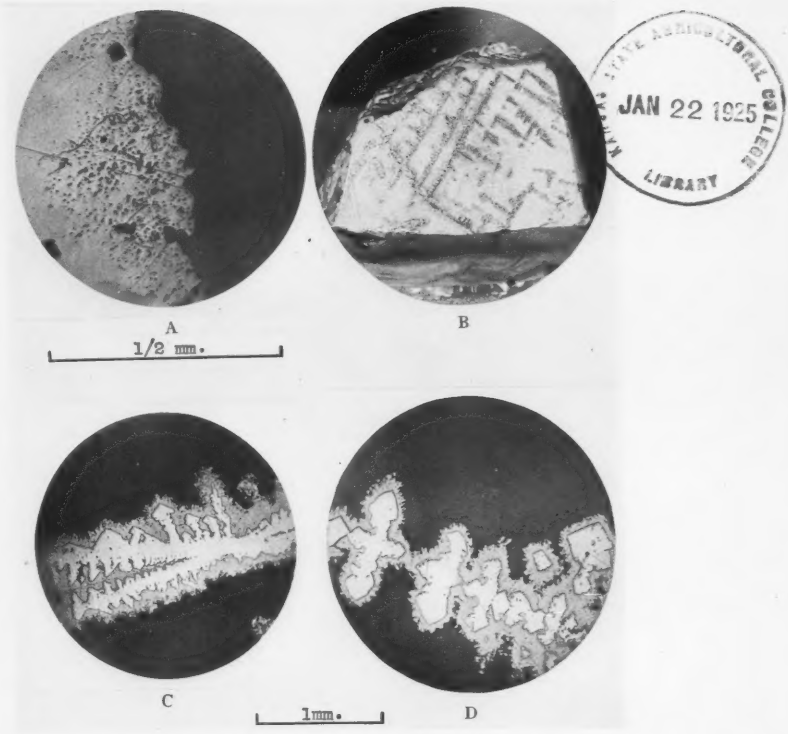
kindly donated by Warren H. Emens, native silver is shown in intimate intergrowth with safflorite(?) and niccolite in the fashion shown in Plate V., *D*. Both safflorite(?) and niccolite *invariably* show their own characteristic crystal faces against the silver, so that obviously the silver could not have replaced these arsenides. In face of this relationship and the extremely intimate manner in which silver, safflorite(?) and niccolite are intergrown, it is difficult to escape the conclusion that the three minerals are essentially contemporaneous.

Niccolite and Breithauptite with Crystalline Outlines against Silver.—Niccolite and breithauptite are commonly associated and show identical relationships to the other ore minerals. Very commonly they show their own crystal faces against native silver, as shown in Plate VI., *A*. Similar relations are shown in ore from the Trehewey Mine (Plate VI., *B*) and the Kerr Lake Mine (Plate VI., *C*) in the Cobalt district proper. In such cases the silver has certainly not replaced the niccolite—in spite of the fact that in the laboratory silver solutions readily attack niccolite with the precipitation of metallic silver. A few niccolite boundaries are slightly and smoothly curved against silver but this is not indicative of replacement since straight crystalline boundaries adjoin in the same or neighboring crystals.

Silver Inclusions in Safflorite (?).—Additional evidence that crystallization of silver was in part contemporaneous with that of safflorite(?) is furnished by the abundant presence of irregular minute silver inclusions in some of the safflorite(?) masses, especially in the border portions of these masses, which were the last to crystallize. Such inclusions are shown in Plate VII., *A*, from the Frontier Mine, and Plates VI., *C* and *D*., from the Kerr Lake Mine.

Silver Crystals within Smaltite in Casey Mine, Cobalt.—In a specimen of ore from the Casey Mine obtained through the courtesy of Warren H. Emens, native silver forms skeletal crystals in smaltite and calcite, as shown (three fourths natural size) in Plate VII., *B*. The pattern assumed by the silver is not in any





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A. Inclusions of native silver and calcite in safflorite(?). Black is calcite. Frontier Mine, South Lorraine.

B. Skeleton crystals of native silver in calcite. Casey Mine, Cobalt. Three-fourths natural size.

C and *D*. Crystalline silver (*S*) enclosed in envelope of smaltite. Black is calcite.

way related to cleavages in the calcite. The silver crystals are enveloped in smaltite as shown in Plates VII., *C* and *D*.[7]

Scattered inclusions of niccolite occur in the silver; niccolite also occurs interruptedly along the contact between silver and smaltite and is the principal cause of minor irregularity in the silver outlines. That niccolite has not been replaced by silver is shown by the prevalence of crystal faces of niccolite against the silver. A little calcite and argentite are intergrown, apparently contemporaneously, with the silver in a few places. Outside the main silver crystals minute inclusions of silver occur in the smaltite, showing that silver deposition did not cease abruptly.

The crystalline silver of this specimen can only be explained as primary.

Relationships of Tetrahedrite.—The microscope shows the presence of tetrahedrite in many parts of the veins of the Frontier Mine, where it is not otherwise visible. In quantities visible to the unaided eye it is found only in a few places. At the locality where it was most abundant, the only associates of the tetrahedrite are calcite, a little quartz, and arsenopyrite. The tetrahedrite, as shown in Plate II., *C*, occurs mainly within, but partly without, the arsenopyrite areas. In places the tetrahedrite within is continuous with that without. Arsenopyrite invariably shows its own characteristic orthorhombic crystal faces against both tetrahedrite and calcite. These relations appear to indicate that arsenopyrite was the first mineral to crystallize assuming the form of numerous partially connected hollow lobes. Then tetrahedrite crystallized mainly within the hollow centers of the arsenopyrite masses, but in part outside of them. Less typical than the relations just described are those shown in another specimen from the Frontier Mine in which the tetrahedrite is unquestionably younger than the gray arsenides. The latter have been fractured and tetrahedrite deposited as a matrix between the angular fragments.

[7] The crystal forms assumed by the silver are similar in general to those described for skeletal crystals of silver and of copper in Dana's "System of Mineralogy," 6th Ed., p. 21, and by A. Sadebeck in *Tschermak's Mittheilungen*, I., Pl. VII., 1878.

Tetrahedrite in general appears to bear much the same age relation to the gray metallics that silver does; in fact, as shown in Fig. 5, it forms a minor component of some silver veinlets cutting the gray metallics.

COMMON MINERALS FOUND IN VUGS.

A few relatively large vugs were exposed at the time of the writer's examination of the Frontier Mine, mainly in the Woods and Watson veins. The Watson vein has proven especially vuggy and at one place the vugs are lined with crystals of white quartz and of calcite, but no metallic minerals. At another place vugs are lined with cobaltite in aggregates of small tubercles, a few calcite crystals being deposited on the cobaltite.

In the Woods vein, a vug 1 by 2 by 3 feet in size was lined with scalenohedral crystals of calcite up to 2 inches in length, which in one place rested upon an aggregate of bismuthinite and arsenopyrite. Similar scalenohedral crystals of calcite collected from the dump show small crystals of chalcopyrite (and rarely pyrite) implanted on and in some cases embedded in them.

ARGENTITE AND NATIVE SILVER IN VUGS.

Argentite associated with wire silver occurs in small vugs a few inches across in the richest ores of the Wood's stope, about 80 feet above the third level. The vein at this locality is rich in niccolite and gray arsenides. The argentite is confined to the walls of vugs where it is irregularly intercrystallized with calcite (which encloses some chalcopyrite) and at its base interlocks intimately with the iron, cobalt and nickel arsenides. It is *not* a coating on these arsenides, and there is no evidence that it is secondary. This argentite appears to be a primary mineral deposited, along with calcite and chalcopyrite, late in the same mineralization period in which the commoner ore-minerals were formed. Some of the argentite shows octahedral crystal faces and some shows a bluish tarnish, suggesting superficial replacement by a little secondary covellite.

In most of the vugs carrying argentite wire silver also is

found. The silver appears to be an alteration product of argentite and is attached to that mineral except where the alteration has resulted in the complete destruction of argentite. The silver "wires" may be more exactly described as curling "teeth," since they are attached to argentite at their larger end and taper towards their free end. Their sides are striated and they are notably porous. If a silver wire is chewed between the teeth it is compacted to a small fraction of its original volume. A shallow depression exists in the argentite opposite the base of every silver tooth, but in some cases this depression is so shallow as to appear as little more than a dulling of a smooth lustrous crystal face of argentite. Between scattered silver teeth the argentite surfaces are often brilliant, unetched crystal faces, but where silver teeth are abundant the intervening argentite is dull and has an etched appearance.

These occurrences of silver on argentite are well below the original ground-water level. The silver is regarded as an alteration product of argentite, but it is not by any means certain that the alteration was the work of descending oxidizing waters. It is well known that in many silver deposits the sulphur of argentite (Ag_2S) has been oxidized by air or oxygenated waters of surface origin, leaving native silver. The reactions that have usually been invoked to account for this alteration postulate acid conditions in which sulphuric acid and ferrous sulphate are present. In the Woods stope the conditions were certainly not acid, for unetched crystals of calcite remain along side the silver teeth. Furthermore the silver teeth have in some of the vugs in the Woods stope been partially *reconverted to argentite.* Several specimens from this stope in the mine office collections and in the collections at the Cobalt office show black teeth identical in form with the silver teeth. Close inspection shows that the cores of these, especially near the base, are still silver and they therefore represent silver teeth converted to argentite superficially, the change sometimes being complete near the tips of the teeth. Near some such argentite-silver teeth calcite crystals have been superficially coated thinly with argentite. To account for

these changes which were subsequent to the formation of the silver teeth, it is necessary to postulate the presence of some sulphide either as a gas or in water solution—presumably either hydrogen sulphide or calcium sulphide. Such sulphides are likely to be found in mine waters of purely surface derivation only under exceptional conditions which do not seem to exist in these deposits and it is therefore questionable whether the development of silver teeth and their subsequent reconversion to argentite were accomplished by downward enrichment.

RUBY SILVER—PROUSTITE.

Ruby silver is rare in the Frontier Mine and none was seen in situ by the writer. A specimen (locality not specified) in the mine collections shows clear ruby-red crystals of proustite (Ag_3AsS_3) 3 mm. long, interlocking with argentite crystals of comparable size but less perfect form. The two silver minerals appear to be contemporary.

In the adjacent Keeley Mine proustite was noted by the writer in ore from Stope D, shortly above the sixth level. It occurs in vugs intercrystallized with argentite. Both these silver minerals appear to be contemporary and primary. There is no evidence that they coat or replace other minerals; on the contrary they interlock irregularly with them. The balance of evidence in these occurrences favors the view that the proustite was deposited late in the primary mineralization.

Unquestionably primary proustite associated with galena ore from the Keeley Mine will be described in the following paragraphs.

GALENA-RICH ORES.

Galena-bearing ores were not seen in place in the Frontier Mine but were noted in the dump of Shaft No. 1. The metallic minerals present in approximate order of abundance, are galena, chalcopyrite, löllingite or safflorite, sphalerite and pyrrhotite. Gangue minerals are quartz and calcite. All these minerals appear to be essentially contemporaneous. The löllingite or saf-

florite is in radiating skeletal crystals intergrown with galena, chalcopyrite or pyrrhotite.

A specimen collected by the writer from the Wood's vein in the Keeley Mine in Stope F, shortly above the seventh level, shows clearly the age relations between the arsenide ores that form the dominant type and the galena ores that are a very minor type. The arsenide ore type carries at this place calcite, arsenopyrite, and cobaltite, with minor amounts of niccolite and chalcopyrite.

Replacing the wall-rock alongside the ore just described and in places cutting that ore in sharp veinlets is a later group of minerals, including

Sphalerite	Pyrrhotite
Galena	Proustite
Pyrite	Carbonates.

Some of the veinlets carrying these minerals are delicately banded parallel in general to their walls. The pyrite is in spheroidal forms with radiating structure and this together with the fineness of texture and the presence of occasional skeletal crystals of sphalerite and galena, suggests relatively rapid crystallization. At one place the following sequence was observed in the bands beginning at the wall of the veinlet:

1. Carbonates.
2. Sphalerite.
3. Galena and proustite with in places some pyrite and sphalerite.
4. Sphalerite.
5. Pyrite in radiating spheroidal forms.
6. Calcite.

Among this group there is no reason to question the primary character of any mineral except perhaps proustite. Since proustite is in many districts a secondary replacement of galena or other minerals its relations here demand close inspection. The close associates of proustite in this ore are galena and sphalerite.

The proustite is found to share in the banded arrangement of the other vein minerals. It shows no tendency to be localized along peripheries of galena or sphalerite areas or along fractures or cleavage directions in these as is usually the case when it is a product of replacement. The contacts between proustite and galena and sphalerite are prevailingly straight crystal faces of the latter two minerals (tetrahedral outlines predominate with sphalerite; the galena shows both cubical and octahedral faces); the proustite cannot therefore be a replacement of either mineral. Occasional skeletal crystals of galena and of sphalerite occur in the proustite. These relationships appear to demonstrate conclusively the primary nature of the proustite.

It is clear that some at least of the galena-rich ores are younger than the dominant arsenide-rich type. Their mineral composition shows clearly that they were primary; pyrrhotite, for example, is never a secondary mineral. Whether they represent a mineralization not connected with the main mineralization or are merely the latest stage in the main mineralization is still uncertain. The fact that löllingite or safflorite, sphalerite, chalcopyrite, and proustite are common to both ore types favors the view that the two mineralizations were related and separated by only a brief time interval.

The abundance of proustite in some of the galena-rich ore is an encouraging feature economically.

PLATES OF SECONDARY (?) SILVER.

In vein No. 1 on the third level of the Frontier Mine, about 30 feet north of the cross-cut to No. 1 Shaft, a little stoping has been done above the level on a pocket of rich ore in Keewatin greenstone. The greenstone bordering the vein here is traversed by small fractures, in some of which plates of native silver, up to ½ mm. thick and continuous over many square inches, have been deposited. This silver is free from arsenic and antimony and is not associated with any other mineral except a little calcite. There is no evidence that it is an alteration from argentite or other silver compound; on the contrary the thinness and delicately

branching character of some of it suggests direct deposition in the native state.

It seems possible that this plate silver is a deposition from descending solutions but if so the depositing solutions were not acid. The quantity of such silver in the mine is very small as contrasted with the silver found within the veins but its occasional presence makes it desirable to closely inspect the wall-rock bordering the veins wherever this has been notably fractured.

SUMMARY AND CONCLUSIONS.

Evidence is presented based upon detailed field and laboratory studies to show that the native silver at the Frontier Mine, South Lorraine, is almost entirely a primary or hypogene mineral. At this mine the primary character of the silver is shown by: (*a*) abundant inclusions of silver in the common arsenides (Plates VI., *D*, and VII., *A*), (*b*) intimate and apparently contemporary intergrowths of silver with sulphides (Fig. 5), and (*c*) textural evidence that no hiatus existed between the deposition of most of the arsenides and deposition of most of the silver.

In ores from mines at Cobalt additional evidence that the silver is primary is found in the presence of skeletal crystals of silver enclosed in smaltite (Plates VII., *B*, *C*, and *D*) and in intimate and apparently contemporary intergrowths of silver and arsenides (Plate V., *D*).

In the ores studied the silver had nowhere been deposited by replacement of the arsenides and this in spite of the fact that in the laboratory the arsenides of iron, cobalt, and nickel are effective precipitants of silver from both sulphate and bicarbonate solutions. The possibility of replacement of arsenides by silver in other ores of the Cobalt district is obviously not excluded.

Much of the silver occupies ramifying ruptures developed in the ores before crystallization of the gray arsenides was completed (Plates III., *D*, IV., *A*, and Fig. 3). The resulting silver veinlets and nests are walled by well-developed crystals of arsenides (Plates V., *A* and *B*, IV., *C* and *D*). These relations show that silver did not replace the arsenides; if it had, their sharp boundaries would have been impaired.

The larger features of the veins at the Frontier Mine indicate that both fissure-filling and replacement of rock by ore minerals have been operative in their formation.

Crystalline argentite and proustite in vugs in the Frontier ores are interpreted as primary.

Teeth and wires of silver in these vugs have clearly developed by the reduction of argentite. It is not clear, however, that this was accomplished by descending meteoric waters, because in places silver teeth have been reconverted superficially or terminally to argentite.

Galena ores associated in minor amounts with the arsenide ores cut the latter and are clearly younger. Both have some minerals in common and may be two phases of a single mineralization period. Proustite is clearly a primary component of the galena ores. The presence of minor amounts of pyrrhotite in these ores is noteworthy.

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THE MAGNESITE DEPOSITS OF MANCHURIA.[1]

KUNITARO NIINOMY.

INTRODUCTION.

In 1913 there were discovered in southern Manchuria [2] a number of deposits of crystalline magnesite, which promise to rival the well-known Austro-Hungarian ones in richness and extent.

These deposits are scattered over a large elongated area that extends northeastly across the southern part of Manchuria, being located in that portion which is known as the Liao-Tung peninsula, and more particularly in the province of Sheng-king. They occur in an area of approximately 60 sq. km. (about 23 sq. mi.) and lie to the east of the town of Ta-shih-chiao, close to South Manchuria Railway. The principal city and seaport Dairen (English Dalny) is situated near the extreme end of the peninsula, southerly from the magnesite area.

At least 13 magnesite deposits are known in the area discussed in this paper.

Investigation of the properties and the commercial value of the magnesite was begun in 1913 by the South Manchurian Railway Company, but as yet only a few of the deposits have been studied in great detail. All of them are owned by the Railway Company.

The field work in the area was carried on by the writer during the summer of 1920, and the laboratory study of the material collected was subsequently made at Cornell University.

Previous Geologic Work.—A number of geologists, chiefly American and Japanese have visited Manchuria from time to time, and published papers on the areal geology of different parts of the province.

[1] The complete paper of which this is an abstract is on file in the Cornell University Library. Presented before Society of Economic Geologists, New York Meeting, May, 1924.

[2] Report of British Consul-General at Dairen, *Board of Trade Journal*, etc., Vol. CI., p. 225, 1918 (Aug. 15), London. Report of U. S. Consul-General at Dairen, Commerce Reports, Vol. I., p. 578, 1920, Washington, D. C.

The first of these observers was Baron F. F. von Richthofen who in 1869 passed through this magnesite area on a journey from Peking to Newchang.[3] He described many typical occurrences of the chief formations, especially those of the Takushan series of the Algonkian, and also noted the large area of Archaean gneiss and granite of this region. According to him the rocks of southern Manchuria are principally Archaean, Algonkian, and Sinian (Cambrian), in age, although there were also noted some younger formations and igneous rocks. These views were agreed to by K. Kimbo[4] in 1893 and T. Ogawa[5] in 1905, and later also by K. J. Bogdanovich[6] in 1900. Blackwelder[7] in 1903 followed v. Richthofen's route across the Liao-tung peninsula, and discovered a new fauna of Lower Cambrian age in what he called the Yung-ning series, but made no mention of the magnesite deposits.

The magnesite deposits were not recognized until 1913, when T. Yoshizawa[8] discovered them near the railroad station of Sha-kang, on the routes formerly followed by v. Richthofen and Blackwelder. The former had called the material a magnesian marble, but the latter did not mention it. Additional deposits were discovered a little later near Ta-shih-chao and Hai-cheng.

Preliminary field reports on these magnesite deposits were made in 1916 by T. Hatcho,[9] and in 1917 by H. Murakami,[10] followed in 1919 by a report on the physical and chemical properties of the magnesite by S. Komori[8] and one in 1921 by K.

[3] "China," Vol. II., p. 71, 105, and 378, 1882, Berlin.

[4] *Jour. Geog.*, V., p. 304, 1893, Tokio.

[5] *Ibid.*, XVII., p. 155, 1905.

[6] Abstract of Russian article in *Trans. Inst. Min. Eng.*, XIX., p. 489, 1900, London.

[7] Smithson. Contrib. Knowledge, XV., p. 85–96.

[8] Report by S. Komori on chemical and physical tests of Manchurian magnesite. Bulletin issued by South Manchurian Railway Company, 36 pp., 1919, Dairen.

[9] Not published.

[10] Preliminary Report on General Geology of South Manchuria, 38 pp., 1917, Dairen.

Hirano.[11] A report on the associated talc deposits was issued in 1921 by S. Shichiri and M. Tachikawa.[12]

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Physiographic Features.—The Manchurian magnesite area can be divided into an eastern and a western part each with characteristic topography.

In the northern half of the eastern part, the summits of the hills are mostly less than 220 meters in height and form low northeasterly ranges from which peaks rise to a height of over 300 meters. The lower southern half of the eastern part represents an eroded peneplain, with a number of low hills, and alluvial deposits filling the valleys between them.

The western half of the area is an almost level alluvial plain with several island-like prominences rising above it.

The physiographic history of the area includes a considerable period of erosion as a result of which the more resistant quartzites and hard schists were left to form prominent hills and ridges, while the softer schists and limestones were worn down to form low hills on a sub-peneplain.

The depressions have since been filled to form a flat plain by marine deposition, underlain by sands and gravels whose fineness increases with the distance from the hills. This last event evidently occurred during a subsidence of the land, following which there was an uplift and further denudation under sub-arid conditions resulting in a reduction of the valley bottoms towards grade, a broadening of the valleys, and a lessening of the valley slopes.

The region, therefore, presents today the features of a late mature to old age stage in a normal cycle of erosion, modified by the presence of the newer sedimentary fill and the effects of renewed denudation under sub-arid conditions.

The only important stream in the region is the Ta-shih river, which flows westward into the Gulf of Pechili. Its discharge is very small except in the rainy season.

11 "On Chemical and Physical Tests of Manchurian Magnesite," Bull. 2 issued by South Manch. Railway Co., 26 pp., 1921, and *Jour. Jap. Ceramic Society*, No. 360, p. 361, and No. 361, p. 414, 1922, Tokio.

12 *Chinese Mining Journal*, No. 53, p. 1, 1921, Dairen.

GEOLOGIC FORMATIONS.

Four geologists, Pumpelly,[13] v. Richthofen,[14] Blackwelder,[15] and Murakami [16] have previously published on the geology of Manchuria.

The geologic sections given by the last three differ somewhat as to details, partly because the subdivisions are not equally clear in all parts of the Liao-Tung peninsula.

These sections as worked out by previous investigators are given in Table I., and in the last column there is given that part of the section found by the writer in the magnesite area.

TABLE I.

		von Richthofen	*Blackwelder*	*Murakami*	*Niinomy*
Quaternary			Volcanic rocks	Loess, sand, gravels	Sand, and gravels
Cambrian		Sinian formation and Korea-granite-porphyry	Fuchou series	Hsiao-fang-shen series	Dikes
			Yung-ning sandstone	Quartzite complex, quartzite and siliceous slate Ferruginous quartzite	(Absent)
		-Unconformity-			
Pre-Cambrian	Algonkian	Takushan series, quartzite, schist, limestone, etc.	Takushan series	Hematite-quartz-schist	Takushan series, quartzite, sandstone, limestone, dolomite, etc. -Unconformity-
		Black-quartzite and hornblende schist		Green schist complex	Schist complex
	Archean	-Unconformity- Gneiss and gneiss-granite	Gneiss complex	Gneiss and granite	(Absent)

[13] "Geologic Research in China, Mongolia and Japan," Smithson. Contrib. Knowledge, XV., pp. 1–128, 1867.

[14] "China," Vol. II., pp. 71 and 378, 1882, Berlin.

[15] "Research in China," I., pt. 1, p. 14, 1907, Washington.

[16] Preliminary Report on General Geology of South Manchuria, 38 pp., 1917, and "Geology of the An-shan Iron Mine District, South Manchuria," 53 pp., 1922; both were published by the South Manchuria Railway Company, Dairen, Manchuria.

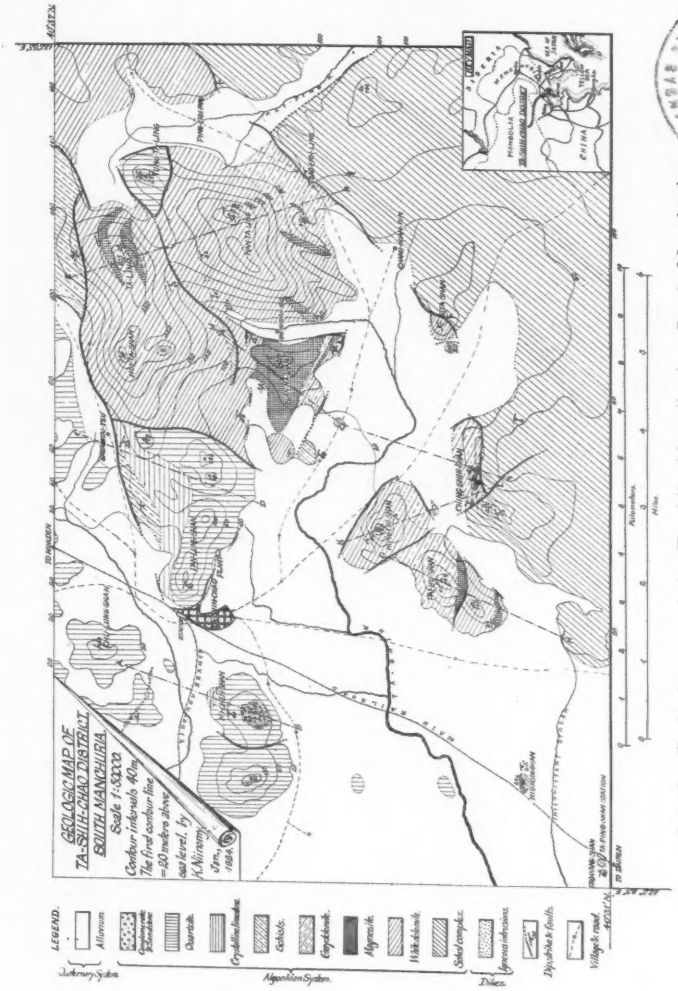

FIG. 6. Geologic map of the Ta-shih-chiao district, South Manchuria.

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Fig. 6 shows the distribution of the geological formations in the magnesite area, and Fig. 7, the generalized columnar section.

Archean System.

There is no evidence of Archean rocks in the magnesite area, but they are abundantly exposed about 15–20 km. east and northeast of Ta-shih-chiao.

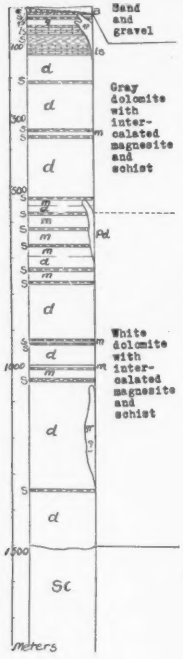

FIG. 7.

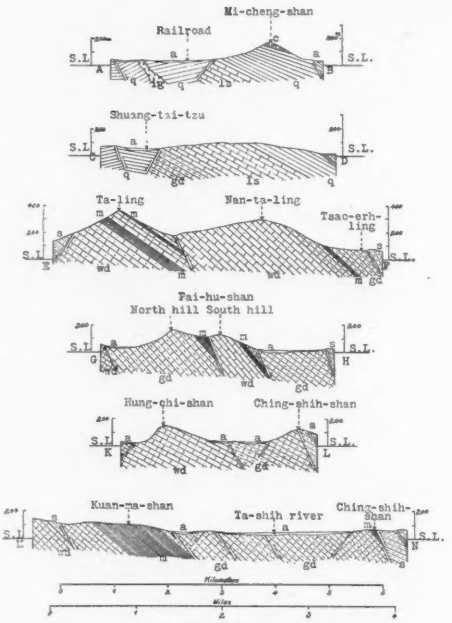

FIG. 8.

FIG. 7. Columnar section of formations in Manchurian magnesite area: *a*, alluvium; *c*, conglomerate; *d*, dolomite; *gr*, granite; *ls*, crystalline limestone; *m*, magnesite; *pd*, porphyritic diabase; *q*, quartzite; *qp*, quartz-porphyry; *s*, schists; *sc*, schist complex.

FIG. 8. Geologic section. Parallel lines indicate approximate dip of each bed: *m*, magnesite; *gd*, gray dolomite; *wd*, white dolomite; *ls*, crystalline limestone; *q*, quartzite; *s*, schists; *c*, conglomerate; *a*, alluvium; *ig*, igneous intrusion; *S.L.*, sea level.

Algonkian.

The Takushan series, so named by von Richthofen, and recognized by the other geologists who have worked in Manchuria, is thought to correspond to the Algonkian system, and the present writer believes that most of the rocks in this area belong to it. It can be divided into two parts: (1) A lower or schist complex, and (2) an upper one composed of quartzite, thin schists, dolomites, limestones and magnesite.

Schist Complex.—The rocks of this lower member are chiefly schists, in which staurolite, talc, and andalusite respectively may predominate. They underlie most of the low, rolling area which occupies the southeast portion of the region studied. Schistosity and shearing are strongly developed and the rocks strike in a northeast-southwest direction parallel with the general trend of the mountain ranges. Thin quartz veins, and lenses lying parallel with schistosity of the formation are common.

The staurolite schist which is found near Ta-shan, is composed of biotite, sericite, and quartz grains, with staurolite crystals sometimes twinned, scattered through it. In thin sections the staurolite shows a yellow color, strong pleochroism and contains numerous small inclusions, while the biotite is found to be often changed to a green fibrous material that is probably chlorite.

The talc schist and andalusite schist occur in the eastern part of Ching-shih-shan.

The former, which is usually minutely plicated, appears megascopically to consist almost entirely of talc, but under the microscope shows associated muscovite and clayey material containing some chlorite as well as numerous small needles and twins of yellow rutile.

The andalusite schist megascopically appears to consist mainly of biotite and sericite, with numerous needle-like prisms of what is apparently an altered andalusite. The reasons for identifying this mineral as andalusite are that it occurs as square prisms, and shows a distinct cleavage parallel to m(110) as seen in thin sections.

In addition, thin sections of the schist exhibit short prismatic crystals of tourmaline, with their longer axes lying parallel with the schistosity.

Quartzite-Schist-Limestone Group.—This group which represents the upper member of the Takushan series, is separated from the lower schist complex by an unconformity. It consists of the following divisions named in ascending order: (1) dolomite, crystalline limestones, and magnesite with thin beds of schist (2) slates and schists with one bed of crystalline limestone, and (3) quartzites, sandstones, and conglomerate. These three divisions overlie each other conformably.

Dolomite, Magnesite, and Crystalline Limestone.—These three rocks, which grade into one another lithologically, are in general clearly stratified, coarsely crystalline, and sometimes even schistose in appearance.

The crystalline limestone lies near the top of the group, and is usually separated from the dolomite and magnesite below by several beds of schist. The upper part (about 10 m. thick at Shuang-tai-tzu) is magnesian, while the lower part of the same thickness is much less so and makes a good lime.

The dolomitic member can be further subdivided into an upper or gray member, and a lower or white one, that contains the magnesite deposits. The total thickness of the carbonate rocks in the area studied is at least 1,400 meters, of which the dolomite forms about 75 per cent., limestone 3 per cent., magnesite 12 per cent., and schist 10 per cent.

Mineralogically the carbonate rocks are quite simple. In thin section they may in their less pure phases show a mixture of calcite, dolomite, and magnesite, and the dolomite and crystalline limestone sometimes exhibit many microscopic grains of rutile, quartz, sericite, and tourmaline. The magnesite may show streaks of flaky graphite, and grains or masses of talc. In most cases, however, the carbonates occur in rather pure masses.

Locally there has been an abundant development of scapolite. This is found at Ta-ling in the lower bed of the more southerly of the two magnesite deposits, and in a bed of gray dolomite at

Hsiao-kao-chang-tun and Ching-shih-shan. The mineral, although soft due to weathering, stands out in relief on the weathered rock surface.

While scapolite has been variously referred to as a product of regional and contact metamorphism, there is in this case no evidence of any intrusive rock in the immediate vicinity, and this together with the fact that the scapolite occurs in a rather narrow bed, leads one to believe that it may be a product of regional metamorphism.

Scattered unevenly through the section of carbonate rocks are a number of thin beds of schist and some slate that in places grade into the carbonate rocks, and the supposition is that they represent metamorphosed argillaceous sediments. The schists are always fine grained, and in most cases contain abundant rutile, tourmaline, calcite, and chlorite as accessory minerals. They can usually be assigned to one of three types, viz., tourmaline schists, chlorite schist, and mica schist, the different types usually forming separate beds. The mica schist at Kuan-ma-shan is interbedded with thick deposits of magnesite and is about 10 meters thick. The mica is chiefly biotite, which is frequently altered to a chloritic mineral. At one locality the biotite occurs as large brown crystals, which lie with their cleavage planes parallel to the schistosity and give the rock a peculiar mottled appearance. Under the microscope they often show alteration to limonite and chlorite.

Schist Member.—Lying between the carbonate rocks and the quartzite-sandstone member is a series of schist beds, 30 meters thick. The writer has put this as a middle member of the upper Takushan series, because of its thickness and extent, rather than considering it to be an upper part of the middle member.

Mineralogically this schist does not differ from the separate and thinner beds of this rock, which are intercalated with the carbonate rocks, since it exhibits tourmaline, chlorite, and biotite varieties.

Quartzites and Sandstones.—This member includes quartzites, argillaceous sandstone, and conglomeratic sandstone, which re-

spectively grade upward into each other. They are well developed at Pan-lung-shan, Mi-cheng-shan, and Tung-ta-shan, as well as in the northwestern part of the area. That at the first named locality has also been noted by Blackwelder.[17]

In thin sections the quartzite consists of quartz grains of usually transparent character, but sometimes containing very fine inclusions arranged either in lines or in cloud-like patches. The former may extend from one grain to the other. Some quartz grains are surrounded by a film of chalcedonic silica, and there may in addition be interstitial sericite. The sandstones consist of rounded grains with a small amount of argillaceous material between them. The conglomerate pebbles which are of quartz, average about 5 mm. in diameter.

The total thickness of the sandstones at Mi-cheng-shan is about 30 meters, and none of them are fossiliferous. They are part of the Takushan series, and not Lower Cambrian as stated by Blackwelder, a fact that seems proven by their having been found under fossiliferous Lower Cambrian beds at Chin-cheng-tsu [18] in the Fu-ksien district which lies to the southwest of the area studied.

Igneous Rocks.

The only igneous rocks exposed within the magnesite area described in this paper are dikes of porphyritic diabase and quartz porphyry.

Diabase.—This occurs as a small dike 5 meters long and less than 1 meter wide which is found cutting the magnesite at Niu-hsin-shan. On the weathered outcrop it is dark green, resinous and rather soft, resembling serpentine. Examination of the surface shows some black prismatic crystals of augite about 2½ mm. long.

Thin sections show the rock to be considerably decomposed, but phenocrysts of plagioclase and augite are discernible. The

[17] "Research in China," vol. I., part 1, p. 88.

[18] Aochi, O., "Geology of Chin-cheng-tsu, Fu-ksien district, Province of Sheng-king (a Part of the Liao-tung Peninsula)," *Chinese Mining Journal*, No. 59, Apr., 1923, pp. 1–19, Dairen, Manchuria.

former, although altered to kaolinite still show albite twinning and zonal structure, and the latter has been altered to chlorite. Cubical grains, perhaps originally magnetite but now changed to limonite are scattered through the groundmass which is a mixture of clayey and chloritic material.

Nothing definite can be stated regarding the age of this dike except that it post-dates the magnesite in age.

Quartz-Porphyry.—This rock forms at least five dikes which cut the quartzite between Mi-cheng-shan and Chu-lung-shan, near the northwest corner of the area. The dikes are in no case over 1 meter wide and under 10 meters long. The rock is light pink or grayish brown in color. In thin sections the phenocrysts are seen to consist of quartz with corroded outlines, orthoclase, plagioclase (probably albite) and muscovite. The groundmass is holocrystalline and shows fluidal structure.

Quaternary.

The Quaternary deposits consist of alluvial sands and gravels. The former are found in the lowlands between the hills and are widely distributed, but the latter occur chiefly on the lower slopes of the hills forming in many cases the upper part of alluvial fans.

There are no available records showing the maximum thickness of the alluvial deposits in the valleys, but in places they are probably as much as 20 meters.

STRUCTURAL GEOLOGY.

The rocks of the magnesite area show both folding and faulting.

Folds.—No large folds are found within the area under consideration, for the rocks in general dip southward, and apparently form the southern limb of an anticline whose axis lies to the north of the mapped area. To the south, there is a syncline but this also lies outside the area described.

Some minor folds were noticed, the largest of these having a span of 7 meters.

Faults.—As the structure sections of Fig. 8 show, faulting is prominent and wide spread in the magnesite area.

There are two principal directions of faulting, northeasterly and northwesterly, of which the former is the more important, not only in the magnesite area but also in the surrounding regions. The position of these faults has been identified by the stratigraphic relations of beds on opposite sides of the fault, by breccias, slickensides, and irregular dips along the lines of displacement.

Northeasterly Faults.—One normal strike fault forms the northern boundary of the main group of magnesite deposits, and dips to the north; the foot wall forms a steep north-facing slope. In this there are exposed a series of beds of dolomite, quartzite, marble, and schist, and they face the quartzite hills about ¼ km. to the north. This fault can be traced for about 100 km. in a northeasterly direction. A second reverse strike fault, extending in the same direction as the first, is found along the northern margin of the schist belt in the southeastern portion of the area, and usually forms the southern boundary of the dolomite deposits.

The fault movement has evidently disturbed the rocks somewhat as shown by the varying strikes and dips adjoining the faults.

There are two minor faults of the same trend as shown in Fig. 6.

Northwesterly Faults.—There are four faults in the area with a northwesterly strike (Fig. 6). Two parallel ones extend from the southern side of Pan-lung-shan to Chan-kuan-tun, and form a graben valley about 2 km. wide, which is filled by alluvial deposits. Near the northwestern end of this area, along the valley, are the five intrusions of quartz porphyry, which by their alignment suggest that they have followed the fault lines. The exact age of the faults could not be determined, although the main ones at least may pre-date the magnesite. The evidence bearing on this is outside the magnesite area. None of these are closely associated with the magnesite bodies. The faults shown in the sections of Fig. 8 are of post-magnesite age, and are all minor ones.

MINERALS OF MAGNESITE AND ASSOCIATED DEPOSITS.

The minerals found in the magnesite area are comparatively few in number and may be briefly referred to.

Dolomite.—Aside from its occurrence in crystalline grains in the dolomite beds, this mineral also occurs as crystals lining cavities in the massive dolomite at several localities, and in the talc at Ta-ling and Ching-shih-shan. Most of the crystals are imperfectly developed, and the largest showed a maximum dimension of about 20 mm. A saddle shaped form about 40 mm. long was found imbedded in the botryoidal talc at Ching-shih-shan. It is possibly not dolomite, but breunnerite the ferruginous variety of magnesite. The dolomite crystals lining cavities in the dolomite are supposed to have been formed by leaching of the rock and redeposition in cavities along the stratification planes.

Magnesite.—This has been noted only in crystalline grains, and not as crystals. The magnesite usually is accompanied by talc, and it includes lenses of schist and slate, which is not true of dolomite. The criteria for distinguishing magnesite and dolomite are referred to on a later page.

Calcite.—This occurs as crystalline grains in the limestone, as occasional isolated crystals in dolomite, in veinlets, and as stalactitic forms attached to dolomite crystals found in cavities in dolomite. The last named mode of occurrence has been noted by other writers.[19]

Quartz.—This mineral is widely distributed in all the rocks except the magnesite. Considerable quartz is found in the dolomite at Hung-chi-shan and Nan-ta-ling. It was probably formed by meteoric waters which may have leached it from overlying rocks now eroded.

A noteworthy occurrence of quartz is found in the dolomite at Kuan-ma-shan, Ta-ling, and other places, where there are com-

[19] von Buch, L., "Renfermant le Tableau Géologique de la parte Méridionale du Tyrol," *Ann. Chim. et Phys.*, XXIII., 1st sér., p. 276, 1823; Grandjean, B. V., "Dolomite und Braunstein-Lagerstätten in untern Lahn-Tahle Neues. Jahrb. Min., p. 543, 1844. Volger, G. H. O., "Ueber die Pseudomorphosen des Fahlerzes, Poggend," *Ann. Phys. u. Chem.*, LXXIV., p. 25, 1849.

pact masses of milky quartz, containing rhombic crystals, now composed of silica and evidently representing replacement of dolomite by quartz. Occasionally the latter preserves the cleavage lines of the former (Fig. 9).

FIG. 9. Quartz pseudomorphs after dolomite, Huang-ni-shan near Shakang railroad station, about 29 km. southwest of Ta-shih-chiao. $\times 5/6$.

Talc.—This mineral occurs in masses in some magnesite deposits, either along the boundary or within the magnesite itself. The talc occurs as isolated grains in magnesite or dolomite, mostly the former. In this case it may be a pseudomorph after magnesite. It also occurs occasionally as botryoidal masses in cavities in magnesite. It is also found in talc schist of the schist complex.

The origin of the talc in the dolomite and magnesite may be as already explained for other similar cases, according to the following formulæ:

$$3\,MgCO_3 + 4\,SiO_2 + H_2O = H_2\,Mg_3\,(SiO_3)_4 + 3CO_2,$$

$$3\,Ca\,Mg\,(CO_3)_2 + 4\,SiO_2 + H_2O = H_2Mg_3\,(SiO_3)_4 + 3CO_2 + 3CaCO_3.$$

These reactions may possibly be due to meteoric waters, or to silica bearing solutions of magmatic origin.

Similar occurrences have been described by Grandjean [20] and Nauck [21] from Göpfersgrün.

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There is considerable CO_2 in the ground water in the vicinity of some of the talc deposits. The silica may have been derived from the decomposition of the associated slates and schists.

A similar origin for talc from schists has been suggested by Redlich and Cornu,[22] for the magnesite deposits of Mantern in Styria.

There seems to be fairly strong evidence that both the magnesite and dolomite are changed into talc for the following reasons: Many crystalline nodules of magnesite, and dolomite (rather rare) are found in the talc quarries of Ta-ling and Kuan-ma-shan. They are usually flattened and lenticular in shape, and are never angular except in the case of redeposition along some fissure where they sometimes form irregular masses. Some crystals of magnesite or dolomite in these nodules exceed 20 mm. in diameter. Under the microscope a section of a nodule is seen to be coarsely crystalline, and each crystal of magnesite is completely covered by a thin veneer of a talcose mineral. The edges of the crystals are sometimes decomposed, and minute fissures filled with talc extend into the interior of the crystals. These nodules are therefore merely remnants of the original magnesite (or dolomite) which were comparatively less fractured and are therefore less replaced.

Chlorite.—This is present as an alteration product of biotite in the schists, slates, and porphyritic diabase.

Scapolite.—Crystals of what is probably altered scapolite, occur in the coarse grained magnesite at Ta-ling, and in the gray dolomite at Hsiao-kao-chuang-tun, and Ching-shih-shan, but they cannot be positively identified as they are almost completely decomposed into micaceous, talcose, and chloritic materials. The

[20] *Neues Jahrb. Min.*, p. 543, 1844.
[21] *Poggend. Ann. Phys. u. Chem.*, LXXV., p. 129, 1848.
[22] *Zeitschr. prak. Geol.*, XVI., p. 145, 1908.

crystals are slender, nearly square, prisms, 10 to 35 mm. long, and 2–7.5 mm. in diameter. The crystals sometimes appear sheared, are commonly brown, gray, or sometimes greenish, specific gravity 2.6–2.8, hardness 2–3, and occasionally a distinct prismatic cleavage.

At Ta-ling this mineral is usually limited to the lower bed of the southern magnesite deposits, while at Hsiao-kao-chuang-tun, and Ching-shih-shan, it has been found only in a layer of the gray dolomite. At the latter locality the scapolite, although very soft, stands out in relief on the weathered surface of the dolomite (Fig. 10). B. Koto [23] who was able to obtain some crys-

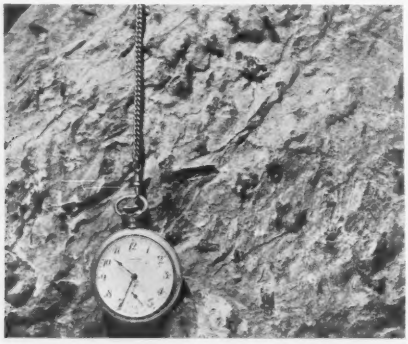

FIG. 10. Scapolite crystals in gray dolomite, Chin-shih-shan. (Photographed by T. Hatcho.)

tals which contained a core of fresh material, states that an examination of their optical properties leads him to believe that they are mizzonite. Although the origin of the scapolite is not definitely known, it is probably a product of regional metamorphism.

Staurolite.—This mineral occurs only as a constituent of the staurolite schist, and has probably been developed by regional metamorphism.

Magnetite.—This occurs in the quartzite beds in the north-

[23] Private communication.

western corner of the district and has no connection with the magnesite.

Limonite.—The limonite may occur as a surface deposit precipitated from meteoric waters flowing from the slates and schists, and as alteration product of pyrite crystals in these rocks.

MAGNESITE DEPOSITS.

The area which includes the magnesite deposits that received most study, extends in a northeasterly direction from Niu-hsin-shan to Ta-ling, and parallels the main structural features. The southern half of this area (about 30 km. long), contains the most important deposits and has been studied in the greatest detail. It is probable that more magnesite may lie to the northeast of the area studied.

The magnesite deposits are found in the dolomite within an area about 15 km. long and 4 km. wide, and are usually elongated in a direction parallel to the strike of the dolomite. They grade into the latter rock at the ends and also at the side where the two are in contact, the only exception being at Pai-hu-shan where a sharply defined lens occurs.

Most of the deposits lie in the white dolomite, and are usually associated with thin beds of slate or schist, though in places the magnesite overlies the dolomite as at Pai-hushan, Ching-shih-shan, and Kuan-ma-shan. The associated schist may grade into the dolomite, but is always sharply separated from the magnesite. Where the magnesite is absent, the schist is absent also.

The only igneous rock found in contact with the magnesite is the dike of porphyritic diabase at Niu-hsin-shan. This does not appear to have produced any contact metamorphism, unless the coarser texture of the magnesite near the contact can be ascribed to this cause.

There is no evidence of bedding in the magnesite, but an indistinct banding is sometimes noticeable, due to the presence of streaks of graphite scales or plates.

Composition of Magnesite.—Many analyses of the magnesite and dolomite have been made, chiefly in the laboratory of the

Manchurian Railway Company,[24] and the following may be taken as fairly representative.

	Insol. in HCl.	Al_2O_3.	Fe_2O_3.	Ca.O	MgO.	Ignition Loss.	Total.	Sp. Gr.
1	1.27	.08	.20	3.09	44.05	51.31	100.00	3.00
2	3.93	.17	.53	6.39	40.75	48.23	100.00	2.99
3	.27	.02	.65	30.23	21.26	47.57	100.00	2.87
4	.70	.00	1.19	.30	47.02	50.79	100.00	3.00
5	1.50	.46	.77	1.67	45.68	49.92	100.00	2.99
6	.56	.20	.72	30.12	21.85	46.55	100.00	2.86
7	2.06	.04	1.04	.90	45.02	50.90	99.96	3.00
8	.78	.32	.50	1.15	46.69	50.50	99.94	2.99
9	.88	.04	1.06	18.20	30.64	49.14	99.96	2.93
10	.70	.51	.20	.42	47.02	51.12	99.97	2.98
11	.96	.44	.56	.90	47.02	50.10	99.98	3.01
12	2.98	.40	.32	.72	44.89	50.72	99.98	3.01

1. Magnesite, Kuan-ma-shan.
2. Impure magnesite, Kuan-ma-shan. Includes some talcose material.
3. Dolomite, Kuan-ma-shan.
4. Magnesite from Niu-hsin-shan.
5. Magnesite from Niu-hsin-shan.
6. Dolomite from Niu-hsin-shan.
7. Magnesite from Pai-hu-shan.
8. Magnesite from Ta-ling.
9. Dolomite from Ta-ling.
10. Magnesite from Nan-ta-ling.
11. Magnesite from 15 km. south of Hai-cheng (outside of the area).
12. Magnesite from 15 km. south of Hai-cheng (outside of the area).

Size of Magnesite Deposits.—The following table is of interest as showing the size of some of the individual deposits.

Of the several magnesite deposits, that of Kuan-ma-shan is the largest, and since it is also more or less typical of the occurrence of this material it may be referred to in detail.

Kuan-ma-shan is a hill rising like a promontory above the surrounding alluvial plain (Fig. 6). The rocks forming the hill are dolomite, magnesite, and some thin interbedded schists and slates, all conformable and dipping 35° S.E.

The magnesite beds form the main part of the hill, and have an estimated thickness of at least 900 meters. The rock varies

[24] "On Chemical and Physical Tests of Manchurian Magnesite," Bull. 1 and 2, issued by South Manchuria Railway Co., 1919 and 1921, Dairen.

in color, texture, and purity, and includes some thin beds of dolomite, thin lenses of talc, and some streaks of graphite. There are also small cavities containing stalactites of dolomite or calcite. In texture, the magnesite ranges from medium to fine. Rhombohedral cleavage is common, but twinning is absent.

	Greatest Length (Meter).	Strike.	Greatest Width (Meter).	Approximate Area (Sq. Meter).
Niu-hsin-shan	320	W.–E.	70	11,200
Pai-hu-shan:				
North	1,050	W.–E.	210	110,250
South	700	W.–E.	110	38,500
Ching-shih-shan:				
West	200	W.–E.	70	7,000
East	400	W.–E.	75	26,250
Kuan-ma-shan:				
Main part	1,900	W.–E.	1,000	1,450,000
South	850	NW.–SE.	220	93,500
Ta-ling:				
North	1,900	W.–E.	190	304,000
South	1,900	W.–E.	190	304,000
Nan-ta-ling:				
West	220	W.–E.	150	16,500
S.W.	850	SW.–NE.	170	106,250
Ssw.	200	SW.–NE.	160	96,000
South	540	SW.–NE.	75	33,750
				2,597,200

Both calcite and dolomite may be present in the more calcareous portions of the magnesite, the former usually as thin laminae, and the latter often as veinlets. Siliceous impurities are present and may be due to either talcose material or opaline silica.

The main dolomite beds lie to the north and south of the magnesite area. The northern dolomite beds are generally white and underlie the magnesite while the southern mass of dolomite is gray, and overlies it. The white dolomite on the north is in contact with mica schist along a fault, the latter rock being on the upthrow side. The gray dolomite passes under the alluvial plain.

The dolomite frequently shows a number of long narrow cavities, parallel with the bedding, that may be lined with crystals of dolomite or stalactites of calcite, but no magnesite crystals were found in them. These cavities are presumably due to the action of meteoric waters.

There are several beds of schist at Kuan-ma-shan; the thickest one, a tourmaline bearing mica-schist is 10 meters, and is exposed for a considerable distance in the quarry near the top of the hill. It is dark green, somewhat chloritized, and contains considerable biotite and tourmaline. Its upper part is strongly schistose, its lower part is dark gray and has a more slaty texture.

Two other types, chlorite schist and sericite schist are exposed in other quarries, and both show an abundance of rutile and tourmaline.

The Ta-ling deposits are next in size to those of Kuan-ma-shan, but unfortunately are located rather remote from the railroad. They are of interest because there are two distinct beds of magnesite in the white dolomite, and also because both the dolomite and magnesite contain considerable massive talc that has probably been derived from one or the other of the carbonate rocks. The largest talc deposit occurs in the magnesite and is about 5 meters thick.

Additional deposits of magnesite are found at Pai-hu-shan, Ching-shih-shan, Niu-hsin-shan, and Nan-ta-ling (Fig. 6).

The following comparisons of the dolomite and magnesite may be briefly summarized:

Magnesite.

1. The beds of magnesite, dolomite and the accompanying schists all show a similar strike.

2. A magnesite bed is usually accompanied by dolomite and schists.

3. Magnesite may overlie or underlie the dolomite or schists.

4. A magnesite bed rarely is in contact with both overlying and underlying dolomite beds, but is usually in contact with only one.

5. There is no clear stratification in magnesite beds even in a bed which is of considerable thickness.

6. There is no distinct line of contact, either megascopically or microscopically, between dolomite and magnesite, except at one locality, Pai-hu-shan.

7. Crystalline magnesite is usually coarse or medium in texture.

8. Magnesite is commonly white or whitish but never uniform in color even in a single hand specimen.

9. The cleavage faces of magnesite are usually bright, even if weathered.

10. The weathered surface of magnesite outcrops are sharper and more jagged than those of dolomite.

11. Magnesite is often accompanied by gray graphite which forms streaks in it. The streaks are usually parallel to the stratification.

12. Magnesite is often changed into talcose minerals.

Dolomite.

1. Dolomite is always distinctly bedded.

2. Dolomite is generally light and uniform in color in a single stratum; light gray (upper strata), and white (the lower strata) are most common; sometimes the color varies from light brown to pink.

3. No distinct streaks of graphite are formed in the dolomite.

4. The dolomite is crystalline, and commonly fine or medium in texture.

5. Calcite and sericite crystals, and quartz grains in the dolomite are occasionally oriented in the same direction; sometimes forming undulating parallel bands. The calcite crystals often exceed 20 mm. in diameter. The quartz in the dolomite occurs both in veins or grains.

6. Some large white dolomite crystals are found in the fine-textured gray dolomite.

7. The face of a dolomite crystal has a dull appearance when weathered.

8. The weathered surface of a dolomite outcrop is often smooth, and sometimes covered by "dolomite ash."

9. Long narrow cavities are sometimes found in the dolomite along bedding planes.

10. Crystals of calcite, dolomite, crystalline quartz, or amorphous limonite may be found in these cavities.

11. Dolomite is occasionally sandy or argillaceous, and often grades into schists.

COMPARISON OF MANCHURIAN WITH OTHER CRYSTALLINE MAGNESITES.

Deposits of crystalline magnesites have been described from Austria,[25] Canada,[26] Norway,[27] Russia,[28] Spain,[29] State of Washington, U. S.,[30] and Manchuria.

Nearly all the magnesite of this type is white or light in color including blue, cream, or pink. Some is mottled gray, and exceptionally almost black (Washington) or streaked with gray, brown, or light pink.

The crystalline magnesite deposits are usually lenticular or in beds, both of which are conformable to the dip of the enclosing rocks which are often dolomite, or crystalline limestone, or both.

Other associated rocks may be serpentine, schists, quartzite, or as in Austria and Canada, gneiss. The presence of basic igneous rocks as important associates as in Canada and Washington is the exception.

The following table shows the associated minerals and rocks which have been noted at the different localities.

[25] Canaval, R., *Mitt. Nat. hist. Landes-mus. Kärnten,* vol. XCIV., p. 268, 1904.
von Foullon, H. B., *Verh. geol. Reichsanst.,* p. 334, 1884.
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[26] Bain, G. W., *Trans. Am. Inst. Min. Met.,* No. 1244–*M,* pp. 1–19, 1923.
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[27] Daumann, E., *Jern-Kontorels Ann.,* 1905, p. 222, 1905, Stockholm.
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[28] Mohr, H., *Montan. Rundsch.,* vol. XI., p. 3, 1919.
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[29] de Lôme, E. D. and de Borbón, C. F. M., *Bol. del Inst. Geol. de Español,* vol. XXXIX., p. 255, 1918.

[30] Jenkins, O. P., ECON. GEOL., vol. XIII., p. 381, 1918.
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TABLE II.

ASSOCIATED MINERALS IN THE CRYSTALLINE MAGNESITE DEPOSITS OF THE WORLD.

Mineral.	Austria.	Canada.	Manchur	Norway.	Russia.	Spain.	Wash.
Dolomite	+	+	+	+	+	+	+
Talc	+	+	+	+	+	+	+
Rumpfite	+						
Serpentine	+	+	+	+	+	+	+
Asbestos				+	+		
Breunnerite	+		?	+	+		+
Bronzite	+			+		+	
Brucite							+
Cacholong						+	
Calcite	+		+				
Diopside		+					
Graphite		+	+				
Phlogopite				+			
Pinolite	+						
Quartz	+	+	+		+	+(flint)	
Scapolite			+				
Tremolite	+			+			
Pyrite	+	+	+	+	+		
Limonite	+		+				
Magnetite		+					
Siderite	+						
Sphalerite		+					
ASSOCIATED ROCK							
Dolomite	+	+	+	+	+	+	+
Marble	+	+	+				+
Schists: mica sericite, etc	+		+	+	+	+	
Argillite, phyllite, or slate			+		+		+
Quartzite	+	+	+	+	+		+
Gneiss	+	+					
Serpentine	+	+(?)	+(?)	+	+	+	
Sandstone			+				
Conglomerate	+		+				
Diabase		+	+		+		
Quartz-porphyry			+				
Porphyroid	+						
Sagvandite				+			

More than ten other minerals were recorded from the magnesite deposits at Veitsch, Austria by Cornu [31] and Redlich.[32]

In Grenville, Canada, several other intrusive rocks were found associated with the magnesite beds by Wilson.[33]

[31] *Zeit. prakt. Geol.*, vol. XVI., p. 449, 1908.

[32] *Idem*, vol. XXI., p. 406, 1913.

[33] *Mem. Can. Geol. Survey*, 98, p. 19, 1917.

From the foregoing table it will be noticed that talc, dolomite, and serpentine are practically the only minerals that occur in all the deposits, and that dolomite and schists are common associates.

When compared on the basis of their chemical composition, it is found that the MgO content of the Manchurian magnesites is equal to that of Austria and Washington, but is less than those of Norway, and higher than those of Canada. The Fe_2O_3 content averages less than in the Austrian deposits, but is higher than those in Washington and Norway. The silica percentage of the Manchurian material is sometimes noticeable, due mainly to included talc, in contrast to the Austrian magnesites where it has been traced to opal.[34]

The known deposits of crystalline magnesite are all regarded as being of Lower Paleozoic or Pre-Cambrian age, except those of Spain, which are replacements of Triassic dolomite.[35]

ORIGIN OF THE MAGNESITE DEPOSITS OF MANCHURIA.

The descriptions given in the preceding chapters indicate that there is some similarity between the different important deposits of crystalline magnesite with respect to their mode of occurrence, and, to some extent, their associated rocks and minerals. But while in the case of the Quebec, Austrian, and Washington deposits, the geologists who have investigated them seem to think that the evidence for some one mode of origin is quite conclusive, it may be questioned whether in the case of the Manchurian deposits, the proof is sufficient to establish with certainty any one of several possible hypotheses.

In order to clarify the discussion of origin, the geologic and structural conditions will be briefly summarized:

The Takushan series which carries the magnesite deposits consists of a lower and upper member. The former is made up of a variety of schists; the latter contains the following rocks in ascending order: (*a*) dolomite with magnesite; (*b*) crystalline limestone; (*c*) slates and schists with one bed of limestone; (*d*)

[34] Leitmeier, H., "Doelter's Handbuch der Mineralchemie," I., p. 229, 1912.

[35] Lôme, E. D. de, and Barbón, C. F. M., *Bol. del Inst. Geol. de Españo*, XXXIX., p. 255, 1918.

quartzites and sandstones. There are several beds of schist (*a*) and (*b*). There are also local beds of schist and slate in the dolomite, and they always accompany the magnesite, being not infrequently on top of it, but sometimes forming bands within it. These schists in the magnesite are in part biotitic, and in part chloritic, the chlorite being an alteration product of the biotite.

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The thickness of the schists found on top of the magnesite ranges from one to ten meters. The thickness of the corresponding magnesite deposits varies from a few meters to about forty meters. In one case, at Kuan-ma-shan, where the schists are interbedded with the magnesite, the apparent total thickness of the schists is a few scores of meters, and the total thickness of the magnesite about 900 meters.

The only igneous rocks associated with the magnesite are, one dike of porphyritic diabase, apparently less than 1 meter thick, in contact with it, and 5 dikes of quartz porphyry not cutting the magnesite but located near the northwestern corner of the area studied.

Granite of later age than the quartzite,[36] outcrops at several points around the magnesite area, the nearest outcrop being about 15 kilometers from the magnesite deposits. There is no definite proof that it underlies the magnesite area, hence its rôle in the development of the magnesite must be somewhat hypothetical.

The schists contain such minerals as tourmaline, staurolite, and andalusite. The limestones and dolomites occasionally contain microscopic grains of rutile, sericite, and tourmaline, and the dolomite in addition, scapolite.

The dolomite has been replaced locally by quartz. Talc is found occurring pseudomorphic after dolomite and magnesite, in botryoidal masses in magnesite, or as irregular deposits between schist and magnesite. The members of the Takushan series have been broken by a number of faults as shown in Figs. 6 and 7.

A comparison of the Manchurian magnesite deposits with those of Austria, Canada, Washington, Norway, Spain, and Russia, shows that metamorphic rocks, such as crystalline dolo-

[36] von Richthofen, F. F., "China," II., pp. 83 and 107, 1882.

mite, crystalline limestone, and talc, are common to practically all of them. Later quartz is also a common associate. Whatever theory of origin is advanced should explain the formation of the magnesite, the talc, and the quartz.

The constant association of the magnesite with chloritic schists may at first appear to have some significance because of the possibility that the magnesia may have been leached from the schist and carried into the dolomite to replace the lime. For a time this view appealed to the writer. If true, it would be necessary to consider the source of the water that acted as a transporting agent, and to look for evidence of leaching in the magnesia-bearing schist. It hardly seems likely that cold descending water could have performed this work, hence, if the water came from a meteoric source, it probably descended first to some unknown depth where it became heated and then returned towards the surface, leaching the schists on its way. This theory postulates that the chloritic schist was the source of the magnesia, and it is quite evident that there are certain objections to it. In the first place there is hardly enough schist as compared with the magnesite to have supplied sufficient magnesia to alter so much dolomite to magnesite, and secondly the schist itself where found in contact with the magnesite shows no evidence of having been so leached.

A second possibility is that the dike of diabase porphyry may have supplied magnesia-bearing solutions. This implies an origin similar to that suggested for the Washington deposits.[37] Here again the quantity of igneous rock visible is exceedingly small and one hesitates to pronounce it the source of all the magnesite in the region.

A third possible source is the granite. As already pointed out, this is not definitely known to underlie the magnesite deposits, but the fact that it crops out on three sides of the area together with the presence of some quartz porphyry dikes within the district suggests that it may also underlie it.

[37] Jenkins, O. P., ECON. GEOL., XIII., p. 381, 1918.

G. W. Bain [38] has suggested that a similar rock was the active agent in the case of the Quebec deposits. One might, of course, question whether a rock like granite would be likely to supply magnesian solutions, but this may not be necessary. The writer suggests that the granite may have supplied hot solutions which leached magnesia from the dolomite or probably even the chloritic schists at depth, and on rising nearer to the surface replaced the lime of the higher-lying dolomite, converting it into magnesite. He admits freely that there is no experimental proof that such a change may occur, but it seems as reasonable as other replacement processes sometimes suggested. The question may also be raised of the possibility that the dolomite, if attacked by hot, possibly carbonated solutions coming from the granite might be leached of its lime, leaving magnesium carbonate. If this is a correct view, the leaching of lime from the dolomite should leave it porous and this is not the case. Consequently it appears more logical to assume that the lime of the dolomite was replaced by magnesia.

That the solutions which emanated from the granite carried silica is not impossible; not only may they have contributed to the silicification of the dolomite, but perhaps also aided in the formation of the talc. If this last explanation is correct, it would seem that the silica-bearing solutions came later, because the talc, in some cases at least, is proven definitely to have formed later than the magnesite.

There still remains to be considered the curious close relation of the magnesite and schists. One can easily understand that the solutions if they came from the granite would follow a path of least resistance, which in this case would be either along the foliation planes of the schists, or along the contact between the schist and the rock now converted into magnesite. There is also the possible view that since some of the major faults may predate the magnesite, the solutions from the granite could have risen along lines of displacement. Opposed to this, however, is the fact that few of the magnesite bodies are near the major lines of

[38] *Trans. Amer. Inst. Min. and Met. Engrs.*, No. 1244–*M*, p. 1, 1923.

faulting. Some of these solutions may also have been responsible for the development of the scapolite, rutile, and tourmaline found in the dolomite.

That meteoric water may have played a later rôle in the rearrangement of some of the material in these deposits is shown by the fact that within the dolomite there are a number of small cavities, commonly elongated parallel with the bedding planes, and apparently formed by solution. Lining these cavities are crystals of dolomite and calcite, with occasionally talc or limonite. There was no evidence of enrichment of magnesia along these fractures as was noticed in the dolomite of the Aspen district, Colorado, by Spurr [39] or in the Washington magnesite by Weaver.[40]

If this last-mentioned occurrence of talc is due to surface waters, then it would appear that the talc found in the carbonate rocks had originated in two ways, the massive talc presumably being formed by magmatic waters, and that in the solution cavities by others of meteoric origin.

MINING AND USES.

Although there is a large tonnage of magnesite in the area described in this paper, probably over 200 million tons, comparatively little development has as yet taken place.

The chief quarrying has been done at Kuan-ma-shan, and to a lesser extent at Pan-lung-shan, and Niu-hsin-shan.

A calcining plant for producing caustic and dead-burned magnesite has been erected at Pan-lung-shan for treating the magnesite from that locality, while a kiln for producing dead-burned magnesite from the Kuan-ma-shan rock was built at Dairen.

The two following analyses give the composition of: 1. Crude magnesite from Niu-hsin-shan, and 2. the dead-burned product from the same rock.

[39] Spurr, J. E., "The Aspen Mining District, Colorado," U. S. Geol. Survey, Monog. XXXI., pp. 210–211, 1898.

[40] Weaver, C. E., "Mineral Resources of Stevens County," Washington Geol. Survey, Bull. 20, p. 322, 1920.

	(1)	(2)
SiO_2	0.60	2.86
Fe_2O_3, Al_2O_3	1.66	4.32
CaO	1.20	2.58
MgO	45.62	88.92
Loss on ignition	50.88	1.28
	99.96	99.96

Up to the present, the Manchurian magnesite has been used for making refractory bricks, and lignoid floor cement. The latter use especially is growing.

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PARAGENESIS OF MARCASITE.

W. H. NEWHOUSE.

PRESENT IDEAS CONCERNING THE ORIGIN OF MARCASITE.

In recent years there has been a general tendency among students of ore deposits to consider marcasite as a mineral of supergene origin. Usually the solutions which deposited the marcasite are referred to as "cold acid solutions."

Two instances may be noted where a hypogene origin has been assigned. Lindgren [1] has suggested a possible hypogene origin for it at the National Mine, National Mining district, Nevada; Ransome describes marcasite which he thinks is hypogene from Goldfield, Nevada.[2]

Hypogene is used in this paper according to Ransome's [3] definition to denote hot, ascending solutions. The marcasite at Joplin, Missouri, would not be classed as hypogene in this sense by most geologists to-day since it is generally held to have been formed by cold solutions.

The rather universal acceptance of a supergene origin may be traced to two causes. Its widespread occurrence in clays, shales, slates, etc.,[4] is often indicative of an origin by circulating groundwater presumably acid and cold in nature. Some recent writers have mentioned it in descriptions which are illustrative of an undoubted supergene origin.

Buddington [5] in describing sulphides from Tasmania Claims, Yakobi Island, Alaska, says "Marcasite is secondary and replaces the pyrrhotite forming an intricate network of veins."

[1] W. Lindgren, "Geology and Mineral Deposits of the National Mining District, Nevada," Bull. 601, U. S. Geol. Survey, 1915, p. 45.

[2] F. L. Ransome, "The Geology and Ore Deposits of Goldfield, Nevada," Prof. Paper 66, U. S. Geol. Survey, 1909, pp. 169–170.

[3] F. L. Ransome, Contributions to Economic Geology, Bull. 540, 1912, p. 152.

[4] C. Hintze, "Handbuch der Mineralogie," 1898, pp. 816–833.

[5] A. F. Buddington, paper in press.

Gilbert[6] found marcasite replacing pyrrhotite from specimens collected near the surface at Ducktown, Tennessee, Gossan Lead, Virginia, and Rossland, British Columbia. Polished sections of sulphides from Ducktown, Tennessee show "Grains that were originally pyrrhotite bordered by hard firm marcasite and cut by parallel bands of marcasite to form a sort of grating." . . . "In many cases instead of forming this grating structure the marcasite works outward forming spheroids or ellipsoids in the pyrrhotite. These spheroids usually show one or more concentric cracks as if there had been some loss of volume during their crystallization. . . . The contact with the surrounding pyrrhotite is usually represented by a narrow space as if some soft material had been removed in polishing."

Specimens from the open pits at the top of the sulphide ore from Gossan Lead, Virginia, show an exactly similar development of marcasite. Gilbert[7] remarks that "All the evidence points to the fact that the solutions from which the mineral (marcasite) was deposited were acid, perhaps strongly so."

The second reason for placing it commonly as a supergene mineral is to be sought in some recent experiments performed by workers in the Geophysical Laboratory.[8] These show a very direct relation between the acidity and temperature of a solution and the form of FeS_2 deposited by it. Hot, alkaline solutions produced pyrite while cold, acid solutions favored the deposition of marcasite. With the usual conception of hypogene solutions as being hot and alkaline one would not a priori expect to find hypogene marcasite if these experimental results were considered.

PURPOSE OF THE PRESENT PAPER.

Several occurrences of marcasite have been found which point to an origin by hypogene solutions. These occurrences will be

[6] G. Gilbert, "Oxidation and Enrichment at Ducktown, Tenn.," *Trans. Am. Inst. Min. and Met. Engs.*, 1924, No. 1318.

[7] *Loc. cit.*, p. 9.

[8] E. T. Allen, J. L. Crenshaw, and J. Johnston, "The Mineral Sulphides of Iron," *Am. Jour. Sci.* (4), vol. 33, 1912, pp. 169–236.

described briefly and they will be compared with the occurrences of undoubted supergene origin. The common intimate association of earthy carbonate with the marcasite will be pointed out and some inferences drawn as to the nature of the depositing solutions. The probable colloidal origin of some of the marcasite will be noted.

IDENTIFICATION OF THE MARCASITE.

In the case described of the spherical masses and lath-like aggregates, the mineral was carefully separated from the other minerals and treated with nitric acid. In each case a marked amount of sulphur was obtained as compared with that obtained from an equal amount of pyrite. In several cases a check was made with an equal amount of marcasite from Joplin, Missouri. The solutions obtained from the unknown marcasite and the check marcasite were similar so far as the eye could determine.

The color of all forms is distinctly lighter than pyrite in polished section. Megascopically, it has the color of marcasite on both broken and natural surfaces. Under the microscope one form from Angangueo, Mexico, shows the marcasite crystal form.

The reactions on polished section, under the microscope, check with those given by Davy and Farnham.[9]

SOME OCCURRENCES OF MARCASITE.

Angangueo Michoacan, Mexico.—Some ores from this locality were sent to the Mass. Institute of Technology by Mr. John Barry. No geological description of the deposit from which they were taken is available. The occurrence of marcasite in these ores is of considerable interest due to the complex order of deposition of the minerals as shown in polished section under the microscope. The ore is a massive, somewhat banded mixture of pyrite, pyrrhotite, arsenopyrite, chalcopyrite, sphalerite, galena, marcasite, with later manganosiderite veins up to 1 to 2 centi-

[9] W. M. Davy & C. M. Farnham, "Microscopic Examination of the Ore Minerals," 1920.

meters wide which cut across the sulphides. Quartz forms small veinlets 0.5 centimenters wide in and along the manganosiderite veins. In places the quartz forms small crystals several millimeters long lining vugs in the massive ore and in the carbonates. Pyrargyrite is present, in the main later than quartz. No trace of oxidation is present. Polished sections show pyrite often as small euhedral crystals with sharp outlines surrounded by the other sulphides. Pyrite appears to be the first mineral deposited, closely followed by arsenopyrite. Pyrrhotite fills in between these two earlier sulphides and occasionally embays them. Galena and sphalerite occur in irregular masses later than the pyrite, arsenopyrite, and pyrrhotite. The sphalerite occasionally veins the galena. Little age difference is apparent. Tetrahedrite (?) and chalcopyrite, both appear to be later than the sphalerite. The first is present in small amount in the ores examined. A grayish cream-colored mineral is present in very small amount and often forms very narrow borders around the sphalerite. It could not be positively identified.

Marcasite is present in two distinct forms one of which is later than and replaces the other. In general both have replaced pyrrhotite. The earliest form often is built up of concentric shells which form a more or less globular-shaped mass (Fig. 11). Replacement of these spherical masses by the later form of marcasite and also by manganosiderite have partly destroyed the spheroidal outline. Many of the masses of early marcasite show no concentric rings and form merely irregular masses. These masses are composed of very small grains as observed under high power microscope. Around the borders of the irregular masses occasional scattered grains may be seen encroaching on the pyrrhotite.

The second type of marcasite forms parallel lath-shaped aggregates which often show many small crystals along the edges of the laths (Fig. 11). These laths often cut across and replace the earlier spherical marcasite. Manganosiderite fills in the spaces between these lath-shaped aggregates and occasionally forms veins cutting across them. It appears to be contempo-

raneous with and partly later than the marcasite. Pyrite crystals border the edges of some of these carbonate veins.

Proustite and pyrargyrite are present in small amount later than the carbonate veinlets. The two minerals appear to be contemporaneous.

FIG. 11. M = marcasite; m = lath-like aggregates of marcasite crystals; c = carbonate (dark mineral) filling in between marcasite and veining it. Angangueo, Mexico. × 20.

The general order of deposition is as follows: Pyrite; Arsenopyrite; pyrrhotite; galena and sphalerite; tetrahedrite and chalcopyrite; marcasite with concentric structure; marcasite forming lath-like aggregates; manganosiderite overlaps with the marcasite and the later pyrite; pyrite; quartz; pyrargyrite and proustite.

Freiberg, Germany.—A specimen from the collection of the Massachusetts Institute of Technology shows banded pyrite, arsenopyrite, and sphalerite. Arsenopyrite occurs as euhedral crystals in these bands. On one side of the specimen evidently next to an open fissure, euhedral crystals of arsenopyrite project with later crystals of galena, sphalerite, marcasite, quartz, and manganosiderite resting upon them. The marcasite forms small tabular crystals which rest chiefly upon the arsenopyrite.

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A crust of small milky white quartz crystals covers part of the specimen. Some of these quartz crystals rest upon the marcasite crystals and there is no doubt about their being later. Manganosiderite is present in small brownish crystals of rhombohedral habit which often rest upon the quartz crystals.

Crean Hill, Sudbury, Ontario.—A specimen in the collection of the Institute from this locality is of massive marcasite with a vein about one centimeter wide cutting across it. Crystals of marcasite nearly a centimeter long border the vein. The vein is filled with carbonate and quartz deposited in the main in the order named, but probably with some overlapping. The carbonate is chiefly composed of calcium with some manganese and iron.

Kokomo, Colorado.—Some specimens collected by the writer from the Michigan mine dump and others collected from the Free American prospect at Kokomo show the development of marcasite in massive pyrrhotite, pyrite, sphalerite, and galena ore. Pyrrhotite is the chief mineral present with some earlier pyrite in it. In some cases considerable sphalerite is distributed through the pyrrhotite. The development of marcasite in these ores is in most cases observed very closely related to a development of carbonate. The occurrence is of two types.

One type forms concentric shells up to about 0.5 centimeters thick surrounding and partly replacing small pyrite crystals in the pyrrhotite. Replacement of the pyrrhotite appears to have been stronger than that of the pyrite. Where in contact with pyrite or pyrrhotite it forms sharp close contacts, but it is often separated from the pyrrhotite by a sideritic carbonate. This marcasite does not show such marked spaces between successive concentric shells as does the type to be described later. The sideritic carbonate appears to be contemporaneous with and later than the marcasite. In this type it invariably accompanies the marcasite (Fig. 12). It often forms veinlets usually short and broad which cut across the marcasite.

Pyrite often occurs in small crystals scattered in the marcasite along the margins of the carbonate veinlets. It also forms vein-

lets a fracture of a millimeter across between successive shells of the marcasite.

The second type of marcasite was found best developed in the specimens from the Free American prospect. It was also found in specimens from the Michigan Mine dump but not in connection with the first type.

FIG. 12. Marcasite (*M*) from Kokomo, Colorado, showing concentric structure, with carbonate veins closely associated, and the development of pyrite (*p*) in small scattered crystals along part of carbonate veinlet. ×15.

Small globular masses of marcasite up to 2 to 3 millimeters in diameter occur in the massive pyrrhotite and pyrite ore. They are scattered through the pyrrhotite and are occasionally grouped around small pyrite crystals. Many very minute interlacing veinlets often form a network in the pyrrhotite connecting the spheroids. The veinlets usually show a grill structure where well developed. They sometimes cut across sphalerite, but not the pyrite.

Open spaces are often noticeable around the globules and in the center of the veinlets. Some of the specimens show oxidation to limonite.

However, some specimens show the development of a carbonate in the small grill veinlets (Fig. 13). The carbonate was identified by some small fragments which under the petrographic microscope show rhombohedral cleavage, high birefringence, and symmetrical extinction.

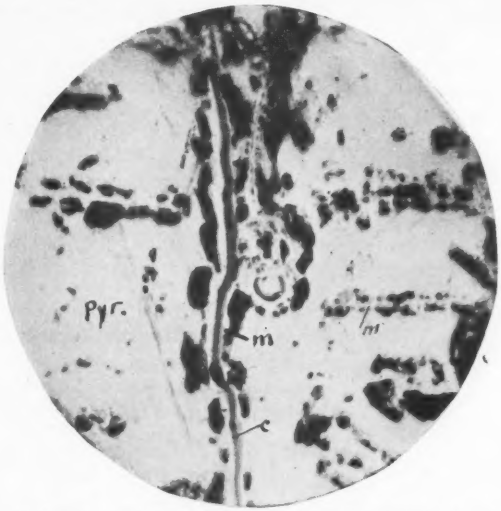

FIG. 13. Marcasite (*m*) forming lattice veinlets in pyrrhotite (*pyr*) with carbonate vein in center of one. Michigan Mine, Kokomo, Colorado. × 60.

Friday Mine, San Diego, Cal.[10]—Tolman and Rogers describe this ore as follows:

A brass yellow mineral occurs in veinlets and reticulate masses as a replacement of pyrrhotite. This was called pyrite by Calkins, but more probably it is marcasite. The marcasite gives the impression of being a very late mineral. It is usually extensively developed along calcite veinlets which occur as a net of intersecting stringers cutting all the other minerals.

National Mine, Nevada.—Lindgren [11] describes this occurrence as follows:

[10] C. F. Tolman, Jr., and A. F. Rogers, "Study of the Magmatic Sulfid Ores," 1916, p. 40.

[11] W. Lindgren, *op. cit.*, p. 44–45.

Marcasite is, however, abundant and occurs throughout the vein in and out of the rich shoot, but always as coating, crystallized or mammillary, on the joints and fissures in the quartz, or is dusted on the pyramids of quartz crystals in small druses. . . . The secondary sulphides, then, comprise marcasite, pyrargyrite and stibnite, and also realgar and orpiment. No gangue minerals appear to have been formed simultaneously with these sulphides. It is concluded that these sulphides were deposited from cool solutions long after the vein had been formed . . . the presence of much marcasite, taken in connection with the scarcity of primary pyrite, might indicate deposition by weak ascending solutions. . . . Observations made by the writer at the El Oro mines of Mexico seem to show that marcasite may be deposited by neutral and weak calcium carbonate solutions having a temperature of about 35° C.; and here also the deposition is distinctly a later phase than the vein formation proper.

Gemini Mine, Tintic, Utah.[12]—

The ore minerals consist of coarse galena, much zinc-blende, a little enargite, marcasite?, and pearcite. Their deposition was accompanied by the formation of a little quartz in small clear crystals, seemingly the last mineral to form. . . . It is, therefore, held that the ores of the Gem Channel were deposited after the principal phases of the mineralization were completed but before active oxidation had begun. It can not be asserted that they were formed by descending solutions, but they were probably formed by cooler solutions, ascending or descending.

At Cobalt, Ontario, marcasite occurs[13] in an intricate mixture of proustite, pyrargyrite and calcite. It occurs in fine divergent forms and is believed to be later than the silver minerals.

Iron Queen Mine, Jerome, and Bradshaw Mountains Quadrangle, Arizona.—Lindgren[14] describes marcasite from this locality as follows:

This mineral is found in the partly oxidized ore, and it is possible that its development just antedated the active oxidation, and that it was formed by descending solutions. The marcasite occurs in small reniform masses, which replace sphalerite, pyrite and gangue . . . there are open spaces between the concentric structures suggesting that colloid of iron sulphide

[12] W. Lindgren and G. F. Loughlin, "Geology and Ore Deposits of the Tintic Mining District, Utah," Prop. Paper 107, U. S. Geol. Survey, 1919, pp. 179–180.

[13] F. N. Guild, "Microscopic Study of Silver Ores," ECON. GEOLOGY, vol. 12, 1917, p. 317.

[14] W. Lindgren, "Ore Deposits of the Jerome and Bradshaw Mountains Quadrangle," U. S. Geol. Survey. In press.

has replaced the minerals, later taking up sulphur and crystallizing as marcasite. . . . The solutions could not have been acid as they replaced quartz as well as sulphides.

CHARACTERISTICS OF SUPERGENE MARCASITE WHERE DEVELOPED IN MASSIVE PYRRHOTITE ORE.

A number of examples which have been mentioned show characters in common.

Specimens collected near the surface from a number of places show minute ramifying veinlets of marcasite which cut across the pyrrhotite and connect with globular masses of marcasite built of concentric shells. Limonite is sometimes found associated with this type of marcasite. Open spaces are common around the spherules and along the veinlets.

In specimens from the Michigan Mine, and from the Free American prospect, Kokomo, Colorado, the development of carbonate along minute grill forming veinlets was observed (Fig. 13). The occurrence described by Tolman and Rogers from the Friday Mine, California, may be of this type. This development of carbonate with and later than the marcasite is of considerable interest. The marcasite has the same minute reticulate veinlets as the clearly supergene marcasite, described by Gilbert and the writer.

The presence of the carbonates indicates that the solutions forming the marcasite could certainly not have been strongly acid in nature. The formation of carbonate by supergene solutions has been noted by Graton and McLaughlin,[15] by Bonillas and Tenney [16] in supergene copper sulphide zones.

According to Emmons: [17]

Acid solutions descending through sulphide ores decrease in acidity, where oxygen is excluded; later they become neutral, and ultimately alkaline.

[15] L. C. Graton and D. H. McLaughlin, "Ore Deposition at Engels, Cal.," ECON. GEOLOGY, vol. 12, 1917, pp. 1–38.

[16] U. S. Bonillas, J. B. Tenney and L. Fuchere, "Geology of the Warren Mining District," *Bull. Am. Inst. Min. Eng.*, 1916, pp. 1451–1457.

[17] W. H. Emmons, "The Enrichment of Ore Deposits," Bull. 625, U. S. Geol. Survey, 1917, p. 149.

The deposition of the marcasite and carbonate probably took place in this case, then, by descending waters which had lost their acidity. The marcasite surrounded by open spaces may have been formed similarly with carbonate and as oxidation and acidity progressed downward the carbonate was leached out leaving open spaces. The other alternative is that some of it may form in the distinctly acid descending waters as suggested by Gilbert.[18]

[18] G. Gilbert, *op. cit.*

CHARACTER OF HYPOGENE MARCASITE.

It may be well to summarize the salient features of some of the specimens described.

The marcasite from Angangueo, Mexico, occurs in two distinct forms, the first in reniform or sometimes merely irregular masses partly replaced by the later marcasite, which consists of lath-like aggregates of crystals. The spaces between these laths are filled with manganosiderite. Veining of these two minerals by manganosiderite with the development of a pyrite border along the veinlet takes place. Quartz forms veins up to one centimeter wide later than the manganosiderite. It also lines vugs in it. Marcasite from Freiberg, Germany, shows later quartz and calcite crystals. Quartz and carbonate vein marcasite from Crean Hill, Sudbury, Ontario. Pyrite crystals occur in the veins later than the marcasite. Specimens from the Michigan Mine, Kokomo, Colorado, showing abundant development of carbonate with the marcasite may possibly be assigned a hypogene origin. Some pyrite is later than the marcasite.

These occurrences show a striking similarity in the associated minerals. Contemporaneous or slightly later carbonate is present in all four cases. In three cases pyrite is later and quartz is later also in three cases.

Veins of earthy carbonate appear to be of frequent occurrence near the close of vein deposition.[19] Quartz is rarely deposited by supergene waters in ore deposits.[20]

[19] J. E. Spurr, "Ore Magmas," 1923, p. 794.

[20] W. Lindgren, "Mineral Deposits," 1919, p. 844.

This sequence of pyrite, carbonate and quartz in overlapping periods of deposition following the formation of the marcasite is indicative of a deposition by alkaline solutions.

Bateman [21] has recently presented a strong argument for the hypogene origin of chalcocite at the Bristol Copper Mine, Connecticut, basing much of his argument on the fact that quartz and calcite accompanied and were later than the chalcocite deposition.

The association of the carbonate with marcasite is so intimate in many cases that a genetic relation must be sought.

The character of the solutions which deposited marcasite and calcite simultaneously at Joplin, Missouri,[22] are conceived by Merwin to have been practically neutral and at ordinary temperature.

The last ebbing phase of hypogene solutions carrying carbonate are then conceived to be the medium which formed the marcasite in the cases noted under hypogene marcasite. In some cases the marcasite appears to have been deposited as a colloid.

CONCLUSION.

In pyrrhotite-pyrite ores two different types of marcasite are formed with a different mineral association.

The association of carbonate, pyrite and quartz with and later than the one type is best explained by assuming a hypogene origin by neutral or nearly neutral solutions.

In connection with the type of solution depositing marcasite the occurrence noted by Lindgren,[23] where it replaced quartz, points to solutions unlike those of the sulphuric acid sulphate type.

The other type is characterized where well-developed by numerous minute veinlets cutting pyrrhotite and other sulphides,

[21] A. M. Bateman, "Primary Chalcocite; Bristol Copper Mine, Ct.," Econ Geology, vol. 18, 1923, pp. 122–167.

[22] H. E. Merwin, "The Simultaneous Crystallization of Calcite and Certain Sulphides of Iron, Copper and Zinc. A Crystallographic Study," *Am. Jour. Sci.* (4), vol. 38, 1914, pp. 355–359.

[23] W. Lindgren, *op. cit.*

often connecting spherical shaped bodies of marcasite. A small amount of carbonate was formed along some veinlets of this type.

The solutions depositing this type of marcasite are in one case neutral or possibly slightly acid. This is where the carbonate is deposited in the veinlets. Where the veinlets and globular bodies show open spaces around them, it may mean that earlier carbonate has been dissolved or what is more likely that the deposition has taken place from cold acid descending waters before the level of neutrality was reached.

The concentric structure of the globular bodies is probably due to the marcasite having been deposited as a gel, with the later taking up of sulphur, crystallization and the development of the concentric structure probably partly due to contraction.

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GEOLOGY OF THE OIL FIELDS IN JAPAN.

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INTRODUCTION.

PETROLEUM and natural asphalt have been known in Japan for twelve hundred years, but were first called by the names of burning water and burning earth respectively. As early as the beginning of the thirteenth century wells were dug by hand at Kurokawa in the province of Echigo, where certain people were granted rights over the oil-producing locality in exchange for the payment of certain taxes to the Governors of the Province. In the middle of the nineteenth century the refining of petroleum was attempted on a small scale in the Echigo province. It is now fifty years since the modern development of the oil industry started. In 1871 the first oil company was organized in Japan and trial wells

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under the management of American drillers were drilled in the provinces of Shinano and Echigo but all were unsuccessful. Following this effort, numerous pits and hand-dug wells were operated in various places and refineries were erected.

During the years 1876–1880, a geological survey of oil lands under the direction of B. S. Lyman was made for the Government, and oil was exploited in many places by test borings, the total production reaching 25,000 barrels in 1882. The present industry, however, was not assured until 1891, when the Nippon Oil Company was organized and opened a flowing well at Amaze, Echigo province, by the American system of drilling. This discovery gave an impetus to the development of the industry, as well as showing the decided advantages of the new system of drilling over the old and tedious method of boring.

Three years after the opening of the Amaze oil field, productive oil deposits were found at Higashiyama, Echigo province, where there were many hand-dug wells. Early in the year 1878 the Nishiyama oil field was discovered, and in 1900 and 1902 the Kubiki and Ojiya oil fields were opened in the same province. In 1900 the International Oil Co. (a branch of the Standard Oil Co. of New Jersey) interested itself in the oil industry in Japan and drilled a number of wells, principally in Hokkaido, but on the whole with disappointing results.

Production in the year 1902 reached 1,250,000 barrels. The greatest yearly production was about 2,653,510 barrels in 1915; since then production has gradually dropped. Towards the end of 1899 the Japanese Government decided upon another geological survey under the direction of the Imperial Geological Survey, and this survey is being continued at the present moment. In 1908 the rotary system of drilling was applied at the Nishiyama oil field, Echigo province, marking an epoch in the oil industry of Japan. Then followed the rapid and successful development of many oil fields in the provinces of Echigo and Akita. So rapid was the development of the Akita oil fields that their production became nearly equal to that of the Echigo oil fields, which were older and very much larger.

GEOGRAPHICAL DISTRIBUTION OF OIL IN JAPAN.

The principal oil-yielding belts in Japan extend from Hokkaido to Echigo province, almost parallel to the coast of the sea of Japan, and from Echigo province south into the province of Shinano, disappearing near Nagano City, but reappearing on the Pacific coast of the Province of Totomi.

In Hokkaido the oil belts extend south from Noshap peninsula at the northeast end of the province of Kitami, passing through the provinces of Teshio, Ishikari, Iburi, and Hitaka, all of which are on the eastern side of the so-called Central Zone of Depression. Crossing the Tsugaru strait, the oil belts continue in to northeast Honshu and thence through the provinces of Mutsu, Ŭgo, and Ŭsen, reaching as far as the southwestern part of Echigo province.

TABLE I.

CORRELATION OF THE TERTIARY FORMATIONS OF OIL FIELDS IN JAPAN.

Hokkaido Oil Fields.		Akita Oil Fields.		Echigo Oil Fields.	
(*a*) Lower Tertiary (Eocene-Oligocene).....	Coal Measure.				
(*b*) Middle Tertiary (Miocene).....	Black Shale Series (Poronoi Series).				
(*c*) Upper Tertiary (Miocene-Pliocene).....	1) Sandstone and Conglomerate Series.				
	2) Dark Gray Shale Series (Wakkanai Series)	Lower Division	Green Tuff Silicious Shale Black Shale	Lower Series	Black Shale and and Tuff Alternation of Shale and Sandstone
	3) Gray Shale Series	Middle Division	Gray Shale Sandy Shale	Middle Series	Gray sandy Shale
	4) Sandstone Series	Upper Division	Sandstone	Upper Series	Shale, Sandstone Conglomerate
(*d*) Uppermost Tertiary (Pliocene)	Sand, Gravel and Clay		Clay, Sand		Clay, Sand, Gravel

GEOLOGICAL OUTLINE OF OIL FIELDS.

Petroleum deposits in Japan are found exclusively in Tertiary formations. These formations have been studied in detail by many geologists, and it is clear that, although there are certain different peculiarities in the oil-bearing strata in the various districts, they have, on the whole, similar characteristics and are of the same geological horizon.

Correlation of the Tertiary sediments of the important oil fields in Japan such as Echigo, Akita, and Hokkaido, is as follows:

THE HOKKAIDO OIL FIELDS.

Geologically Hokkaido is divided into two parts by the so-called Central Zone of Depression. The oil-bearing Tertiary formations differ in character in each district. In the western part they contain much pyroclastic material, and in some cases it is difficult to make a comparison with those of the eastern part.

The Tertiary formations in Hokkaido overlie Cretaceous formations, for the most part unconformable. They are divided into four classes:

Lower Tertiary (Eocene-Oligocene)	Coal measures.
Middle Tertiary (Miocene(?))	Black shale series. (Poronai series)
Upper Tertiary (Miocene-Pliocene)	Sandstone and conglomerate series.
	Dark Gray Shale series. (Wakkanai series)
	Grey Shales series.
	Sandstone series.
Uppermost Tertiary (Pliocene)	Sand, Gravel, and Clay.

Lower Tertiary (*Coal Measure*).—The Lower Tertiary is represented by the coal-bearing series, which is characterized by many coal seams, plant fossils and a brackish water molluscan fauna. The series consists of shales, sandstones and conglomerates with intercalated marly layers and tuffs. The shale is black

or dark grey in color and is in places calcareous; when dried it easily breaks into fine particles. The sandstones are dark, white or greenish in color and are generally composed of quartz grains, but some are tuffaceous or argillaceous. The conglomerate is characterized by its brilliant reddish or greenish tint. The tuffs are composed of minute particles of colorless glass. These sediments are considered to have been deposited in shallow sea water, lagoons or in fresh water.

The lower Tertiary strata show many signs of oil in the provinces of Teshio and Ishikari, but no important deposit has been found in them. The coal seams which they contain are of value.

Middle Tertiary (*Poronai Series*).—The Middle Tertiary unconformably overlies the lower Tertiary formation, and is itself overlaid conformably by the Upper Tertiary formation. It consists of shale with intercalated thin sandstones and conglomerate in the lower parts. It is easily distinguished from the coal measure by lithologic and faunal characteristics. The shale is dark or black in color and is massive, but when exposed to the weather it crumbles easily. Conchoidal or onion shaped fractures are common.

The fossils found in this formation, which are all marine, are as follows:

Nucula poronaica Yok.
Lucina Poronaiensis Yok.
Venericardia compressa Yok.
Tapes ezoensis Yok.
Pecten sp.
Pectunculus sp.
Cardium sp.
Yoldia sp.
Nucula sp.
Venericardia sp.
Venus sp.
Tapes sp.
Leda sp.
Cytherea sp.
Tellina sp.
Mya sp.
Natica sp.
Nassa sp.
Buccinum sp.
Dentalium sp.
Capulas sp.
Echinoidea sp.
Pecten stanfordensis Arnold.
Turritella Wadana Yok.
Phyasira bisecta Courad.

The thickness of this black shale is about 1,000 feet. In some cases tuffs and agglomerates can be seen, but they are thin.

The Middle Tertiary formation contains oil in many places in the provinces of Ibŭri and Ishikari, but no important deposit has been found up to the present.

Upper Tertiary.—The Upper Tertiary formation is a marine deposit and is lithologically divided into four sections. From bottom to top these are:

1. *Sandstone and Conglomerate Series.*

This series conformably overlies the middle Tertiary formations. It consists of sandstones and conglomerates, the sandstones being grayish white or light green in color and are arkosic or contain many fragments of the older rocks. The conglomerates are generally dark and are composed of pebbles of Paleozoic sedimentary rocks, granite, and diabase. Thin beds of andesitic agglomerate and tuff are intercalated in the series.

Many oil seepages are found in the series, but no rich oil deposit has been met with.

2. *Dark Gray Shale Series (Wakkanai Series).*

The dark gray shale series consists of thick dark gray shales with marly layers, marly nodules of large size and thin sandstones. In the shales, hard bands alternate with soft bands, each a few feet in thickness. The hard shale is usually calcareous and contains quantities of magnesia. The thickness of the series does not exceed 15,000 feet. It is characterized by numerous *Choncocele disjuncta* Gabb, and in addition carries a large molluscan fauna and a few plant fossils.

3. *Gray Shale Series.*

The change from the dark gray shales to this series is transitional, and no demarcation line can be drawn between them. The upper part of the underlying series is soft, having few hard parts, and passes gradually into the gray shale series, which is massive and does not show stratification. The shales contain many diatoms and few mollusca. The following forms are found in numbers 2 and 3.

Choncocele disjuncta Gabb.
Cardium graelandicum Chem.
Ostrea gigas Thumb.
Pecten laetus Gould
Tapes rigidus Gould
Nucula sp.
Pecten jessoensis Jay
Pecten Swiftii Arnold.
Tellina nasuta Conrad.

4. *Sandstone Series.*

This series is in the uppermost part of the Upper Tertiary rocks. It consists of fine-grained quartz sandstones with intercalated conglomerate beds.

Volcanic activity continued from the Middle Tertiary period to the Upper Tertiary period, andesite and dacite being erupted.

There are many oil seepages in the Upper Tertiary formations, and they are especially abundant in the gray and dark gray shales. The principal oil-containing strata in Hokkaido are found in them, and rich oil deposits occur in the province of Ishikari, Kitami, and Teshio.

Uppermost Tertiary Formation.—The Uppermost Tertiary occupies a narrow area of low hills or table land along the eastern borders of the Teshio plain. It is composed of alternating layers of sand, clay, and gravel, and unconformably covers the Upper Tertiary. Sand and gravel are the principal layers. The formation resembles the Diluvial deposits in lithological nature.

Geologic Structure of the Tertiary Formations.—The Tertiary formations in Hokkaido have been repeatedly subjected to severe orogenic forces and are much folded or deformed. Consequently, from the province of Kitami to the province of Oshima there are many anticlinal and synclinal structures. The general direction of strike is NNE. or NE. and the dips vary from place to place, from 20 to 70 degrees. During the deposition of these strata, there was violent volcanic activity causing local disturbances to the structure, or changing their nature by volcanic ejectamenta.

The Lower Tertiary formation (the coal measures), is, in general, complexly folded and faulted, showing that it had received more orogenic movement than other later Tertiary formations, which as a rule are gently folded. The Lower Tertiary forma-

tion is not of importance from the point of view of possible oil production.

In the area occupied by the Upper Tertiary formation there are many oil districts along anticlinal folds. In Ishikari province, there are two principal anticlinal axes running almost parallel from North to South. The easternmost, called the Toshibet anticline, has an axis about 13 miles long, and dips on either side of less than 20 degrees. Some of the many oil wells bored along the anticline produced as much as 250 barrels a day. The western anticline, called the Atsuta anticline, runs along the shore line of Atsuta and has a length of six miles. The strata, which, like those of the Toshibet anticline are dark gray and gray shales, dip not more than 20 degrees on either side of the axis. Several test borings were made on this fold, but no rich oil deposit was struck.

There are two long anticlinal folds extending south from Kitami province to Teshio province. The Koitoi anticline on the east has a length of 17 miles and is composed of dark gray and gray shales. The inclination on either side of the axis ranges from 10 to 20 degrees. Several wells have been drilled on it and some of them less than 1,100 feet deep reached oil pools. The Wakkanai anticline on the west is principally composed of the Wakkanai series and is 8 miles long. The inclination on either side of the anticline does not exceed 20 degrees. Two or three wells have been bored on it and fairly rich oil pools were found at a depth of 2,500 feet.

In addition, in the provinces of Iburi, Hitaka and Ōshima there are many anticlines along which test borings have been made, but as no rich oil pool was found all were abandoned.

The total production of oil in Hokkaido does not exceed 7,000 barrels annually.

THE AKITA OIL FIELDS.

Like the Echigo oil fields, the Akita oil fields are important in Japan. They are in the province of Akita, in the northwest part of Honshiu, facing the sea of Japan. The oil fields parallel the

coast line for about 128 kilometers, and the capital city of the province is in the centre of these fields. The surface of the oil districts is occupied by hills or low mountains not over 300 meters in height which have a general northeasterly trend. These hills and mountain ranges usually coincide with the anticlinal folds in Tertiary strata and the valleys between them are mostly synclinal.

The oil-bearing strata in the Akita oil fields are divided as follows:

Upper Tertiary Formation:

(*a*) Lower Division (Miocene)	1. Green tuff series. 2. Silicious shale series. 3. Black shale series.
(*b*) Middle Division (Miocene)	4. Gray shale series. 5. Sandy shale series.
(*c*) Upper Division (Pliocene)	6. Sandstone.

Uppermost Tertiary Formation—Clay, Sand.

Upper Tertiary Formation.—(*a*) Lower Division: (1) Green Tuff series. The lowest of the Tertiary formations in the Akita oil fields is the green tuff series. The series is light green in color, and is compact and hard; the upper part is silicious and grades into the silicious shale series. The green tuff series contains thin beds of lignite, silicified wood, and in the upper portion, a conglomerate bed, characterized by having many *Pecten* sp. (2) Silicious Shale series. This series consists mainly of dark grey or brown shale and is remarkable for its intercalated volcanic rocks, such as basalt, andesite agglomerate, tuffs, tuffaceous sandstones, and calcareous nodules. This series has a thickness of 500 meters and grades into black shale in the upper part. Fossil fish bones and scales, radiolaria, diatoms, and spores of monactinellidæ are found in this series. (3) Black Shale Series. This series overlies the silicious shale, and there is no clear line of demarcation, as they gradually merge. The series is composed chiefly of black-colored shales with intercalated tuff, tuffaceous

sandstones, and calcareous nodules. Diatoms and sponges are contained in the series. In the upper part of this series is a tuff zone 400 meters thick, which consists of pumiceous tuffs and alternating layers of compact tuff and sandstones. It has a thickness of 400 meters.

These three series of the Lower division are continuous deposits. The silicious shales are thought to be metamorphosed facies of the black shales. It is evident that during the deposition of the Lower division, or later, there was violent volcanic activity with intrusion of many volcanic rocks and deposition of the pyroclastic rocks.

(*b*) Middle division: (4) Gray Shale Series. This series overlies the black shales of the Lower division, and consists principally of gray shales with thin tuff and tuffaceous sandstones. This series contains many coscinodiscus and sponges.

(5) Sandy Shale Series. The upper parts of the Gray Shale Series become sandy and grade into the Sandy Shale Series. This series consists of thick gray tuffaceous sandy shales and also contains many tuffaceous sandstones and calcareous nodules. In the lower part of the series many sponges are found. This division has a thickness of 1,000 meters.

(*c*) Upper Division: (6) Sandstone Series. This series consists of gray tuffaceous sandstones with thin layers of gravel and soft shales. It conformably overlies the Middle division. Many shell fossil beds are found, and these are remarkable for the abundance of *Turritella* sp. It is thought that these fossil beds correspond to the Turritella beds of the Echigo oil fields. Probably after the lower division had been deposited, the sea became shallower and the middle division was then deposited.

The fauna found in the sandstone series are as follows:

Thyasira bisecta Conrad.	*Turritella* sp.
Pectunculus sp.	*Natica* sp.
Pecten sp.	*Arca* sp.

Uppermost Tertiary Formation.—This formation is composed of unconsolidated clay, sand, and gravel layers. It generally oc-

cupies the peripheral zones on anticlines, or the synclinal basins, and is always unconformable with the lower beds. The nature of the sediments of this formation and the unconformable relation to the older Tertiary formations indicate some geological gap between them.

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Oil deposits are found in the lower and middle divisions of the Upper Tertiary formations. In the lower division, the upper parts of the silicious shale series contain oil, and in the middle division, the lower parts of the grey shale series contain oil. Tuffaceous sandstones and fractured parts of the silicious shales provide rich oil bearing zones. In the black shale series tuff and tuffaceous sandstones are important oil bearing strata. Oil seepages are numerous in the lower part of the Middle Division, but oil in commercial quantity has not been obtained.

The most productive oil zones are found in the lower part of the black shale series and in the upper part of the silicious shale series. Oil deposits are confined to the anticlinal or domal structures.

Volcanic rocks are met with in the lower and middle divisions. They consist of basalt, andesite, dacite, and liparite; these volcanic rocks caused lithological changes in the character of the Tertiary sediments and in some cases it is believed that they have had some influence on the accumulation of oil, judging from the structure of the strata which they have intruded.

There are many oil fields in Akita province and among them the Kurokawa, Toyokawa, Michikawa, and Uchimichikawa fields, are the most important.

Structure of the Tertiary Formation.—The general strike of the Tertiary formations in the Akita oil fields is NNE.; the strata in most cases are gently folded with dips not exceeding 30 degrees. The Kurokawa oil field is three miles south of Akita city, and is famous for a gusher which produced 10,000 barrels a day. The oil field is surfaced by gray shale and has an elongated dome structure; the inclination of the strata averages 20 degrees. The Toyokawa oil field is in black shale. The structure is that of a terrace, and the oil occurs in fractured zones of

the rock. The Michikawa oil field is in gray shale, which forms an elongated north-trending dome; the oil deposits being found in the domal structure at many depths. At Uchimichikawa oil field, there is found the alternation of sandstone and shale of the middle division; the structure is anticlinal.

THE ECHIGO OIL FIELDS.

The oil-bearing strata of the Echigo oil fields belongs to the Upper Tertiary formations and is divided into four series:

Upper Tertiary:

(1) Lower Series (Miocene)	(*a*)	Black shale (with tuff and sandstones).
	(*b*)	Alternation of shale and sandstones.
(2) Middle Series (Miocene)		Gray sandy shale.
(3) Upper Series (Pliocene)		Shale, sandstone, and conglomerate (with tuff).
Uppermost Tertiary (Pliocene ?)		Clay, sand, gravel.

These series are conformable marine deposits or littoral deposits, except the uppermost series, which lies unconformably over the others, being loosely deposited or having cross-bedding; many writers consider them to be Diluvial deposits.

The Lower Series: The oldest beds in the Echigo oil fields, usually occupy the central parts of the anticlinal structures.

(*a*) Black shale forms most of this series, the thickness being over 6,000 feet. Intercalated are thin sandstones and fairly thick beds of white or bluish tuffaceous sandstones, known locally as "Shiro," meaning white stone, which is the principal oil-bearing stratum. The thickness of the tuff sandstone varies from 20 to 500 feet. Fossils are rare, but certain kinds of brachiopods, fish bones, shark's teeth, and a few shells have been found in various localities.

(*b*) Alternation of shale and sandstone is a facies of the black

shales, being a transitional zone from the Lower series to the middle series. The alternation is a local deposit in some oil fields; the total thickness attains 2,000 feet and is quite barren of fossils.

The Middle Series: This series is represented by light gray sandy shale with subordinate layers of medium or coarse grained sandstone. It covers a broad area and its thickness ranges from 1,000 to 2,000 feet. A peculiar fossiliferous limestone, known locally in Nishiyama and Niitsu as "Natsukawa-ishi," is intercalated. The limestone has a more or less lenticular shape, with a thickness not exceeding 800 feet, sometimes being only 30 feet thick. It contains abundant remains of algae as well as shells. The most characteristic fossil is *Lithothammium ramossissinum* Reus, which was discovered for the first time in the Tertiary on the inner zone of the Japanese Arc and is a valuable form for correlating with the Tertiary on the Pacific side or outer zone. During deposition of the series there was volcanic activity in many places, forming agglomerates, and andesite sheets, which are found embedded in the shale.

Upper Series: This series is composed of soft clayey shale, sandstones, and loose conglomerate, together with interlaminated white tuff-clay which contains numerous plant fossils. The series occupies the lower portion along the Shimano river or the synclinal basin at Nishiyama range. The lithological character of the series shows that it was deposited in a shallow sea. In some places andesite sheets and agglomerate layers are intercalated in the series.

Uppermost Series: This series is composed of soft clay, loose sand and gravel, and occurs in a small area of the foot hills of a mountain range. It overlies, unconformably, the upper series and is sometimes taken for Diluvial deposits, but usually is greatly disturbed. Many geologists are inclined to think that it is the uppermost Pliocene, as the fossil *ostrea* sp. was found, but nothing else.

Volcanic Activity.—There was volcanic activity throughout the deposition of all the series. Andesite and its agglomerate are

associated with this series. Mud flows are confined to the southern parts near the volcano Myoko. Liparite is found in the lower series, where it changed the black shale into silicious hard rocks.

The Structure of the Tertiary Formations.—The geological structure of the Tertiary formation in the Echigo oil fields is, generally speaking, simply due to folding, and there are no great faults affecting the general trend of the strata. The general direction of the strike is from NNE. to SSW., parallel to the sea coast. In the districts lying on the western side of the Shinano River there are four anticlines together with subordinate wrinkles, all running parallel from NNE. to SSW.

The Amaze anticline, in the far west, extends northward over the sea as far as Teradomari city, forming low longitudinal undulations. The Amaze oil fields are at its southern end. The Oginojo anticline lying on the east of the Amaze anticline extends slightly west for a great distance along the crest of that range, its western wing being greatly disturbed, with many faults and foldings. The Ojiya oil field is developed along the same anticline and has regular and gentle inclinations of strata. The Higashiyama range represents an anticlinal fold, the axis of which traverses the entire range. Its western wing is greatly disturbed with numerous faults and folds. The Higashiyama oil field, one of the oldest oil fields in Japan, is developed along an anticline. To the northwest of the Higashiyama anticline lies the Omo anticline, running north and south, the Omo oil field being located along the axis of the anticline.

The Niitsu anticline runs from north to south, forming a gentle arch, and a low undulation like a terrace structure lies on its western wing. In the southwestern part of the Echigo oil fields, in the Kubiki district, there are many anticlines, all parallel and most of them short. Some are steeply inclined, but others are only gently inclined, though all generally have steep sides on the western side. The most prominent anticline in the district runs from Gendoji to the north of Yasuzuka through Iwagami. All the oil districts scattered throughout the districts are on the anticlines, especially on those having an elongated dome structure.

SUMMARY.

As stated above, more or less oil is found in almost all the Tertiary formations, and there can thus be drawn a close relationship between the structure, stratigraphy, and the accumulation of oil. Rich oil deposits are, without exception, on anticlinal, domal, or terrace structures. The oil-bearing strata consist of sandstones, tuffs, and fractured shales, and in many cases, oil is found in association with salt water in these strata. There are many oil horizons and oil from these various horizons has different specific gravities, varying from 10° to 50° Baumé, the poorer ore coming from the higher strata. In the oil-bearing strata where volcanic rocks have passed, the oil has deteriorated in a number of cases into a thick, heavy variety, having a gravity less than 10° Baumé. On the other hand, near volcanic rock, a light-colored oil, appearing as though it had been distilled from heavy oil, can be found. Chemical analysis shows that most oils belong to the naphthane series, some containing small quantities of hydro-carbon of the paraffin series, and from the study of optical activity it has been ascertained that all the oils are dextro-rotary, passing a maximum activity of 4.5°–19.8° (200 mm. tube) in the fractions between 220° and 300° C. under the diminished pressure of about 13 mm.

By measuring the underground temperature in the Echigo and Akita oil fields, it is known that the geothermic gradients in the fields have lower values than the normal gradients. The average temperature gradient appears to be approximately 1° C. for every 15 to 25 meters.

As regards the origin of oil in the oil fields of Japan, opinions of the geologists and chemists vary greatly, but it is accepted by all that oil is of organic origin, and had its origin in the Tertiary sedimentary rocks. The black or dark gray shales which are so widely found in the Tertiary formations, especially in the Middle Tertiary, contain much organic matter, and in or near them are found bituminous substances and rich oil pools. These facts suggest that the oils originated in the black or dark gray shales.

The production of oil in Japan during recent years was as follows:

1916	3,008,818 barrels.
1917	2,883,300 barrels.
1918	2,449,531 barrels.
1919	2,380,730 barrels.
1920	2,227,360 barrels.
1921	2,447,000 barrels.
1922	2,004,000 barrels.

IMPERIAL GEOLOGICAL SURVEY OF JAPAN,
TOKYO, JAPAN.

BALANCE SHEETS FOR MINE AND SMELTER PRODUCTION OF DOMESTIC COPPER, LEAD, AND ZINC.[1]

C. E. SIEBENTHAL.

INTRODUCTION.

IT is of course easier to obtain figures showing the production of a single reduction plant serving a certain region than to obtain figures showing the production of the group of scattered and possibly floating miners that supply ore to that plant. Therefore the earlier figures reported by the United States Geological Survey showing the production of metals in the United States are those furnished by reduction plants, though for some years these figures are supplemented by those obtained from reports of transportation companies or commercial agencies. The figures collected from the mines, however, permit a much more exact determination of the distribution of the metals as to source and kind of ore and time of production, and of other details that are of value or interest to the industry, such as the cost, development, and extent of mining and the occurrence of the ore. The practice of collecting statistics of production from the mines, however, is of comparatively recent establishment. Figures showing the mine production of copper, and especially of ores containing the precious metals, were collected for the Western States and for Michigan and Tennessee before 1906, but it was not until 1907 that figures were available to show the mine production of copper, lead, and zinc for the whole country.

The statistics published by the United States Geological Survey to show the smelter production of copper, lead, and zinc are collected by specialists in charge of the work on those metals, through correspondence with each smelting firm. The term "smelting

[1] Published by permission of the Director, U. S. Geological Survey. Presented to Society of Economic Geologists, New York Meeting, May, 1924.

firm " includes not only the regular smelters but every plant that recovers either or all of these three metals in any form from ore—such as electrolytic zinc plants, zinc oxide, sublimed lead, and lithopone plants, chemical works using ore, and copper sulphate plants. Figures showing the mine production in the Eastern and Central States are obtained by mail through inquiries sent from Washington and corresponding figures for the Western States through inquiries sent from the offices of the United States Geological Survey at Denver, Salt Lake City, and San Francisco. Each operating mine is thus canvassed for its output of shipping ore and concentrate, together with the assay content of metal, and from the figures furnished the total metal content of the ores produced is determined. Most of the reports from the mines in the Western States are furnished by operators who make them up from smelter settlement sheets based on individual contracts, and these settlement sheets often show only metal that is paid for. Ores containing copper or lead not paid for are smelted for other metals or used for fluxing and these have a part of their copper and lead content recovered incidentally, so that the smelters may recover a little more copper and lead than was reported from the mines as having been produced. For instance, in the district of disseminated lead deposits in southeastern Missouri the crude lead ore contains a few hundredths of 1 per cent. of copper; the concentrates contain several times as much but at most only 2 or 3 tenths of 1 per cent. This copper naturally is neither reported nor paid for. Nevertheless some of it is recovered in matte at plants smelting these concentrates. When an accumulation of this matte is worked up and sold by such smelters the copper contents are credited to the Missouri mines for that year, but doubtless some has failed to be so credited in past years. The mine reports of copper companies operating their own smelters commonly show recovered copper. From the figures furnished by the other mining companies shipping copper ore or concentrate a deduction from the total copper content reported is made for smelting loss and the remainder is set down as " recoverable copper." Therefore all copper produced by the mines is recorded as recoverable metal.

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Beginning with 1907 a factor to cover smelting losses has been applied to the figures showing the mine production of zinc ore and concentrate and the result has been reported as "recoverable zinc." Beginning with 1921 a similar factor to cover smelting losses has been applied to the mine figures for lead ore and concentrate, and the result has been reported as "recoverable lead."[2] For the purposes of the present paper factors to cover smelting losses have been applied to the figures giving the mine production of lead in years prior to 1921, so that the table showing the mine production of lead, like those showing the mine production of copper and zinc, represents recoverable metal.

The smelting losses vary with the kind of metal, with the grade and character of the ore or concentrate, with the plant, and with the metallurgical practice, so that the factor to be applied in determining the smelting loss must be chosen with judgment. The average loss of copper in a regular copper smelter is from 3 to 5 per cent., and the average loss of lead in a regular charge in a lead smelter ranges from 2 per cent. in soft lead smelters with baghouses or fume collectors to about 5 per cent. in similarly equipped smelters that handle argentiferous lead. The average loss for zinc ranges from about 10 per cent. in high-grade Joplin concentrates to 15 per cent. or more in lower-grade western concentrates. The loss is much greater if a metal constitutes but a small percentage of a charge that is smelted for another metal, as when copper is recovered in a lead furnace, or lead is recovered in a copper furnace.

When figures showing mine production became available it was, of course, highly informing to compare them with the figures showing smelter production, and the comparison served to check each set of figures. It is not to be expected that all the recoverable metal mined in any year will be recovered by the smelters in that year, for there is always more or less lag either in smelting or in mining. In some years smelting will lag and more ore will

[2] The mine production of copper and lead in Colorado, New Mexico, Texas, Wyoming, and South Dakota has been reported as recoverable metal, beginning with 1909.

remain in the smelter bins at the end than at the beginning of the year and the difference will show a "mine excess"—that is, more ore was mined than was smelted. In other years, the demand for metal may exceed the rate of ore production and thus cause a depletion of the stocks of ore and show a "smelter excess." For a fairly long series of years these differences should be compensatory. An underestimate of the loss in smelting, however, will result in an overestimate of the recoverable metal—the mine production—and thus indicate an unduly large "mine excess," and this exaggeration will continue until a proper correction is made in the factor applied, though at times such an increase may be overbalanced by smelter activity. On the other hand, an overestimate of the loss in smelting due to an excessive deduction factor will result in a continuing smelter excess. An increase in the number and capacity of smelting plants, pigment plants, and chemical plants using ore necessarily results in larger working stocks of ore, and in larger quantities of "material in process," each of which, of course, shows up as mine excess, because each increase locks up raw material that cannot be turned into finished product and figure as smelter production unless ore purchases are reduced and ore stocks worked up.

Copper, lead, and zinc smelters often run in with their charges of ore some old or "secondary" material, unless they are far from areas where such metal can be easily obtained. Unless this material is carefully taken into account and distinguished from ore its use will result in an exaggerated smelter output, tending to produce a smelter excess. Only new, virgin, or primary metal should be balanced against the mine production of recoverable metal. Likewise unless careful metallurgical account is kept of the domestic and foreign ore charged, the domestic metal recovered may be wrongly figured, the error tending to either a mine excess or a smelter excess. The smelters are asked to make such distinction, and the care with which it is made determines the accuracy of the statistics.

Care is taken not to duplicate by counting the metal content of a product made from material already counted, such as French

TABLE I.

DOMESTIC COPPER BALANCE SHEET, 1906–1923. (In short tons.)

Year.	Recoverable Copper (Mine Production).			Recovered Copper (Smelter Production).			Mine Excess (+) or Smelter Excess (−).
	Total.	In Exports of Domestic Ore, Concentrates Matte and Regulus.[a]	Remainder Available for Domestic Recovery.	Refined Copper.	In Copper Sulphate.	Total.	
1906.....	458,486	1,600	456,886	448,691	5,345	454,036	+ 2,850
1907.....	423,576	3,331	420,245	413,311	4,233	417,544	+ 2,701
1908.....	478,420	2,012	476,408	459,556	4,837	464,393	+ 12,015
1909.....	563,261	1,471	561,790	532,782	3,919	536,701	+ 25,089
1910.....	544,119	1,946	542,173	535,947	3,761	539,708	+ 2,465
1911.....	577,382	2,223	575,159	550,635	4,504	555,139	+ 20,020
1912.....	624,547	2,206	622,341	601,838	4,944	606,782	+ 15,559
1913.....	617,785	1,463	616,322	618,414	4,284	622,698	− 6,376
1914.....	524,216	1,940	522,276	605,212	4,301	609,513	− 87,237
1915.....	744,036	1,259	742,777	693,853	5,311	699,164	+ 43,613
1916.....	1,002,988	2,806	1,000,182	944,376	7,022	951,398	+ 48,784
1917.....	947,717	2,889	944,828	936,773	6,366	943,139	+ 1,689
1918.....	955,011	1,581	953,430	941,437	3,959	945,396	+ 8,034
1919.....	606,167	324	605,843	716,743	3,942	720,685	−114,842
1920.....	612,275	214	612,061	571,212	3,912	575,124	+ 36,937
1921.....	233,095	175	232,920	304,707	3,323	308,030	− 75,110
1922.....	482,292	113	482,179	452,335	4,504	456,839	+ 25,340
1923.....	[b] 736,783	194	736,589	732,082	3,994	736,076	+ 513
	11,132,156	27,747	11,104,409	11,059,904	82,461	11,142,365	− 37,956 = 0.34%

[a] Recoverable copper figured as explained in text.
[b] Subject to revision.

process zinc oxide or "atomized" zinc dust made from slab zinc. Likewise, care is taken not to omit metal wrongly reported as secondary because it was derived from residues or drosses produced in reducing the ore.

COPPER BALANCE SHEET.

Not all the copper mined in the United States is recovered at home, a small part being exported as "copper in ore, concentrates, matte, and regulus" and recovered in other countries. Prior to July 1, 1915, the gross weight but not the copper content of the material exported was given by the Bureau of Foreign and Domestic Commerce. For several years after 1915 both the gross weight and the copper content were given, but recent reports show only the copper content. The copper content of the material exported in the earlier years has been computed from the average copper content of that exported in the years when both the gross weight and the copper content were given, and the recoverable copper has been figured at 95 to 97 per cent. of the copper content. In the balance sheet (Table I.) this quantity has been deducted from the annual mine production, and the remainder has been set down as the quantity available for recovery in domestic smelters. The domestic smelter recovery is made up of the refined and casting copper produced and the copper content of the copper sulphate produced at electrolytic copper refineries.

For most years the balance sheet shows a consistent mine excess but in three years there were large smelter excesses. One of these occurred in the early part of the war, when the demand for copper outstripped the mine output; one just after the war, when the demand was unexpectedly large and exceeded the mine output by more than a hundred thousand tons; and one in 1921, when copper mining and copper smelting were at a low ebb.

During the eighteen years for which we have statistics the calculated recoverable copper in the ore mined has all been accounted for by the smelters, and in addition a smelter excess of 37,956 tons has been piled up, producing a discrepancy amounting to 0.34 per cent. of the copper recovered. This discrepancy

TABLE II.

DOMESTIC PRIMARY LEAD BALANCE SHEET, 1907–1923. (Short tons.)

Year.	Recoverable Lead (Mine Production).	Recovered Lead (Smelter Production).						Mine Excess (+) or Smelter Excess (−).
		Refined Desilverized Argentiferous.	Soft Lead [a] Non-argentiferous.	Lead in Antimonial Lead.	Lead [b] in Pigments.	Lead Recovered [c] from Exported Ore.	Total.	
1907..	364,715	222,751	129,630	6,551	6,574	——	365,506	− 791
1908..	330,237	180,785	130,881	7,614	7,377	——	326,657	+ 3,580
1909..	385,113	203,149	149,690	7,262	7,292	——	367,393	+17,720
1910..	382,692	206,132	169,270	8,538	7,603	——	391,543	− 8,851
1911..	426,585	200,381	191,614	8,094	7,678	——	407,767	+18,818
1912..	442,126	221,480	171,037	7,325	10,323	63	410,228	+31,898
1913..	483,113	250,578	161,300	12,463	10,998	135	435,474	+47,639
1914..	504,769	311,069	201,725	12,957	11,914	31	537,696	−32,927
1915..	542,098	301,564	205,462	16,410	12,782	137	536,355	+ 5,743
1916..	601,392	316,469	235,759	14,699	13,252	2,001	582,180	+19,212
1917..	628,464	303,679	244,771	13,035	12,870	4,570	578,925	+49,539
1918..	562,402	282,024	257,881	9,220	13,093	1,388	563,606	− 1,204
1919..	429,589	208,751	215,682	8,339	11,179	3	443,954	−14,365
1920..	496,814	220,327	256,522	8,032	15,212	——	500,093	− 3,279
1921..	414,491	187,962	210,260	6,675	9,989	——	414,886	− 395
1922..	477,633	185,191	283,555	5,810	13,892	——	488,448	−10,815
1923..	[d] 545,591	291,760	252,081	9,794	13,612	——	567,247	−21,656
	8,017,824	4,094,052	3,467,120	162,818	185,640	8,328	7,917,958	+99.866 = 1.3%

[a] Includes desilverized soft lead.
[b] Prior to 1919 includes small quantities recovered from foreign ore.
[c] Recovered at Canadian smelters from ores exported from the United States.
[d] Subject to revision.

cannot be interpreted as a smelter excess due to depletion of ore stocks, for the stocks of ore and material in process at the smelters must now be greater than they were at the beginning of 1906, because the recent annual output of recovered copper is about 15 per cent. larger than it was from 1906 to 1910, inclusive. How, then, shall we account for the smelter excess? The explanation, as suggested above, is set forth more fully in the chapter on copper in "Mineral Resources of the United States," 1906, pages 373–374, which describes the method of making the smelter returns to mines, from which the recoverable copper is calculated. It is probable too that some copper was recovered from low grade ore and not reckoned in the smelter returns. The discrepancy between the total mine production of copper and the total smelter recovery for the whole period of 18 years is so small, however, that, whatever may be its cause, it is practically negligible. The fact that many companies operate both mine and smelter tends to keep the figures showing recoverable and recovered copper close together and to keep down the necessity for large working stocks of ore and hence tends to reduce mine excess. The higher value of copper as compared with lead and zinc also tends to keep down a discrepancy by causing closer attention to be given to assay results, to smelter returns, and to smelter recovery by independent operators and smelters.

LEAD BALANCE SHEET.

The price of lead in the United States has generally been higher than in foreign markets, so that domestic ore has been practically all smelted at home; besides, a tariff is levied on imports of the product of domestic ore smelted abroad and returned to this country. Small quantities of ore have been exported to nearby Canadian smelters, however, and during the war these exports reached considerable magnitude, though owing to their general unimportance the Bureau of Foreign and Domestic Commerce made no separate enumeration of them, so that it has been necessary to ascertain the quantity of lead they yielded by correspondence with Canadian smelters. No lead ore is known to have been exported to countries other than Canada.

The mine production of lead is given in the balance sheet (Table II.) as recoverable lead, and the figures for years prior to 1921 therefore do not agree with the figures showing the mine production of lead heretofore published for those years by the amount of the deduction for smelting loss. The total domestic recovered lead, or the domestic smelter production, is made up of desilverized lead, soft lead, lead in pigments and in antimonial lead recovered at home and of lead recovered from domestic ore in foreign smelters. A comparison of the mine production and the smelter recovery by years shows that mine excesses and smelter excesses alternate very naturally and that there is a total mine excess such as would be expected in an industry which increased 25 per cent. in output during the period covered by the table. From 1915 to 1917 war prices and the war demands for lead stimulated the mines to extra effort, so that a considerable mine excess was accumulated. The fluctuation in price since those years has been more encouraging to smelter than to mine activity, and there have been six successive smelter excesses. In making zinc pigments containing lead the lead recovered may be derived from the lead in the zinc ore or it may be derived from lead ore added to the charge. For the earlier years included in the table it is impossible to say how much of such lead was of foreign origin, but for the whole period to 1918 it certainly would more than equal 2 per cent. of the total discrepancy. After 1918 no foreign lead recovered in pigments is included in the table.

The factor used for smelting loss must closely approximate the true value, as is evident from the smallness of the discrepancy between smelter and mine production, which amounts to 99,866 tons or 1.3 per cent. of the total lead recovered, and is in all probability largely attributable to increased ore stocks and material in process at new and enlarged plants.

ZINC BALANCE SHEET.

The factor for loss in smelting zinc is perhaps more difficult to determine than the factor for loss in smelting copper or lead, because zinc is recovered directly from ore in so many forms—

TABLE III.

DOMESTIC PRIMARY ZINC BALANCE SHEET, 1907–1923. (Short tons.)

Year.	Recoverable Zinc (Mine Production).			Recovered Zinc (Smelter Production).			Mine Excess (+) or Smelter Excess (−).
	Total.	In Exports of Domestic Zinc Ores.	Remainder Available for Domestic Recovery.	In Slab Zinc Made from Domestic Ores.	In Pigments, Salts, and Zinc Dust Made from Domestic Ores.	Total.	
1907.....	253,017	8,141	244,876	223,745	56,931	280,676	− 35,800
1908.....	234,064	10,443	223,621	190,749	47,281	238,030	− 14,409
1909.....	302,373	4,982	297,391	230,225	52,948	283,173	+ 14,218
1910.....	324,444	7,884	316,560	252,479	50,660	303,139	+ 13,421
1911.....	331,515	7,312	324,203	271,621	43,408	315,029	+ 9,174
1912.....	385,621	9,340	376,281	323,907	62,876	386,783	− 10,502
1913.....	413,824	7,085	406,739	337,252	71,037	408,289	− 1,550
1914.....	415,774	4,444	411,330	343,418	81,254	424,672	− 13,342
1915.....	588,060	333	587,727	458,135	80,939	539,074	+ 48,653
1916.....	703,169	31	703,138	564,338	92,537	656,875	+ 46,263
1917.....	713,556	528	713,028	584,597	100,275	684,872	+ 28,156
1918.....	636,091	25	636,066	482,405	105,342	597,747	+ 38,319
1919.....	548,846	———	548,846	452,272	101,561	553,833	− 4,987
1920.....	587,524	———	587,524	450,045	118,966	569,011	+ 18,513
1921.....	256,746	———	256,746	198,232	57,216	255,448	+ 1,298
1922.....	472,032	678	471,354	353,274	95,788	449,062	+ 22,292
1923.....	[a] 610,394	[b] 1,204	609,190	508,335	119,513	627,848	− 18,658
	7,777,050	62,430	7,714,620	6,235,029	1,338,532	7,573,561	+141,059 = 1.9%

[a] Subject to revision.

[b] The Bureau of Foreign and Domestic Commerce in 1923 did not distinguish exports of zinc in ore from exports of zinc dross and old zinc. Statistics of receipts of recoverable zinc in ore for that year have been obtained from the Canadian smelter.

slab zinc, zinc dust, zinc oxide, zinc salts, and lithopone—and by so many processes—fire reduction and oxidation, chemical solution, and chemical and electrochemical precipitation. Another feature that increases the difficulty is the wide diversity in the character of the zinc ores treated, which have ranged from the crude oxidized ores of Leadville, containing as low as 14 per cent. of zinc, and from the blende-marcasite concentrates of the Wisconsin district, containing 15 to 50 per cent. of zinc, to the zinc blende concentrates of the Joplin district, containing an average of about 60 per cent. and a maximum of 62 or 63 per cent. of zinc.

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Between 1907 and 1914 there were exported annually several thousand tons of zinc silicate (willemite) concentrates from New Jersey, but the exports thereafter were small until 1922–1923 when zinc sulphide ore and concentrates containing 1,882 tons of recoverable zinc were exported from northwestern States to Canada. Close estimates, based upon reports from shippers, have been made of the recoverable zinc content of these exported ores.

The balance sheet (Table III.) shows a normal alternation of mine and smelter excess and a mine excess for the whole period of 141,059 tons, equal to 1.9 per cent. of the entire quantity of zinc recovered. An underestimate of the loss of zinc in smelting would result in an exaggerated figure for recoverable zinc and would show as such a mine excess. But a mine excess, as pointed out before, may be due to other causes, particularly to increased working stocks of ore and of material in process, as a result of increased operations at zinc reduction plants. Again, a part of the output of lithopone and zinc salts, all of which was formerly made from zinc ashes and other secondary materials, is now made from zinc ore, and necessitates additional stocks of ore. Considerable quantities of zinc salts were probably made from zinc ore before 1919, when statistical account was first taken of the output of the zinc so recovered. All these factors would tend to swell the apparent mine excess and are probably sufficient to account for the discrepancy of 1.9 per cent.

COMMENT.

The varying reaction of mine and smelter output to the stimulus of high prices and to the depressing effect of low prices and light demand has a large part in determining whether there shall be a mine or a smelter excess. When price and production are gradually pulling up, the capacity and the output of both mine and smelter will be pulled up correspondingly, and there will be no pronounced smelter or mine excess. A rapid rise in the price of metal quickly stimulates the smelters to greater output, which depletes ore stocks and tends to smelter excess. In order to increase their output greatly the mining companies must repair and reopen old mines or develop new ones and before this work is undertaken they must become convinced that the advance movement is solidly grounded. On the other hand, higher prices may make available ore bodies or parts of ore bodies that were already developed but that could not be profitably mined at the lower prices. When increase in price finally stimulates mine production to exceed smelter production the momentum of operations will drive on despite temporary declines in price until price recession dominates the industry and thus makes a mine excess.

It will be helpful in this connection to note the comparative prices and total annual smelter recovery of domestic copper, lead, and zinc in all forms for the period here considered, as shown in Fig. 14. The production curves show the steady annual growth of the domestic output of each metal up to the beginning of the War, the great expansion through the War, the disastrous slump of 1921, and the recovery since then to more than the pre-War output. The graphs showing annual average prices for the metals might be described in nearly the same terms, except that the recession in price in 1921 was not so pronounced as the slump in production, and that only in lead and zinc has the price recovery reached the pre-War average.

The close of 1913 and the onset of the War found the United States with a mine excess of about 75,000 tons in each copper and lead but with a smelter excess of 25,000 tons in zinc. However,

this smelter excess was offset by stocks of 40,000 tons of slab zinc at the smelters which was increased to 65,000 tons by the midyear of 1914. The country was in a fortunate position as regards the supply of these metals. Except for a flurry at the beginning of hostilities, the prices of the three metals remained low in 1914 and the demands of the War led to a smelter excess in all of them. The next three years were marked by higher prices for copper and lead and 1915 and 1916 by higher prices for zinc.

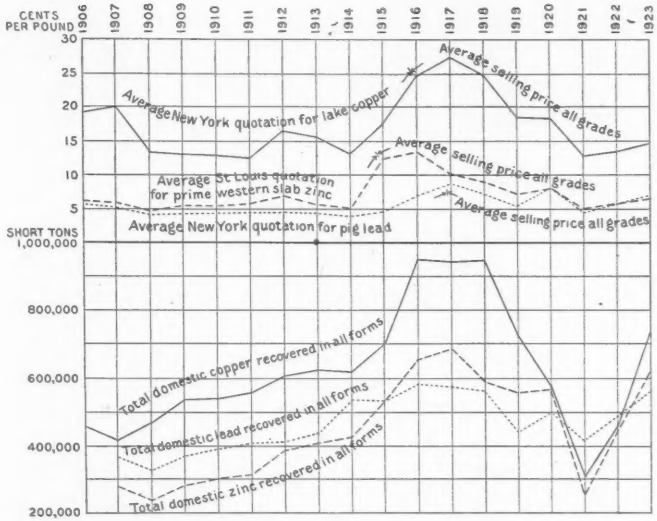

FIG. 14. Annual production and average price of copper, lead, and zinc, 1906–1923.

The result was a mine excess from 1915 to 1918 in copper and zinc and from 1915 to 1917 in lead. The year 1919 was the culmination of 2 to 3 years falling prices in the metals, and in consequence mine output was low and there was smelter excess in all three metals. A temporary betterment in price in 1920 in the three metals resulted in mine excesses in zinc and copper, though there was small smelter excess in lead. The slump in

prices in 1921 greatly reduced mine output in all three metals, each of which registered a smelter excess. The general improvement since 1921 in the prices of these metals is marked by increased output of each; both 1922 and 1923, however, showed smelter excesses in lead, a result apparently of the failure of southeast Missouri mines to keep pace with the increased production of the Western States.

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WASHINGTON, D. C.

EDITORIAL

THE PROBLEM OF THE CUPRIFEROUS PYRITIC DEPOSITS.

THE origin of the cupriferous pyritic deposits, found extensively in metamorphic rocks throughout the world, has long been debated, but it still remains an open question. In Japan, there are many deposits of this category, some of them ranking among the richest and largest in the world; therefore, a brief summarization of the results of investigations may be of some interest to students of ore deposits.

1. Most of the cupriferous pyritic deposits of Japan are found in the terrain of highly metamorphosed crystalline schist complex, called the Sambagawa series by Prof. Koto, probably corresponding to the Algonkian formation in North America. They consist of sericite-gneiss, sericite schist, piedmontite schist, chlorite schist, and graphite-sericite schist, frequently accompanied by such metamorphosed basic igneous rocks as eclogite, amphibolite, antigoritic serpentine, and others. This series is most typically developed in the western limb of the Japanese Arc, with a northeasterly trend, extending from the Tenryugawa district, over the peninsula of Kii and across the island of Shikoku, to Kyushu. The ore deposits are commonly found in lenticular or bedded forms along the planes of schistosity. The largest of this type is the deposit of the Besshi mine in Shikoku, which has a length of more than 1,600 meters along the strike, over 1,200 meters down the dip, and usually is 6 to 10 meters in thickness. It consists of massive cupriferous pyrite and fahlband-like banded ore cut by a pure chalcopyrite vein, and is enclosed in chlorite schists, in close relation to eclogite and amphibolite. Another interesting example of the deposit in the same zone is that of the Seki mine in Kyushu, which is very small but

affords instructive data. It is developed along the contact between chlorite schists and an intrusive mass of serpentine, and is intricately folded and wrinkled, the ore mass often replacing both walls in a complicated manner. On examining, under the microscope, the banded or low-grade ores from these two mines, it is revealed that the crystallization of the constituent minerals and the development of the schistose structure of the chlorite schist have preceded the deposition of ore minerals, so that pyrite and chalcopyrite have partially replaced the components of the rock and filled up the interstices of them, the massive cupriferous pyrite being nothing but a wholly replaced portion. But it is evident that the metallization has occurred at a late stage of the dynamo-metamorphism, *i.e.*, before the cessation of the schist-forming process, because the mineralized zone is intricately folded and contorted with the wall rocks. It is noteworthy that there is no stock nor apophysis of granitic rock to be found in the terrain of the Sambagawa series, and it is inferable that the deposits of this category are genetically connected with the pre-Cambrian basic igneous rocks, which have been metamorphosed into eclogites, amphibolites, and other schistose green rocks during or subsequent to the metallization.

Thus, the cupriferous pyritic deposits, enclosed in the Sambagawa schists, belong to the metallogenetic epoch corresponding to the latest pre-Cambrian period of orogenesis and igneous activity.

2. Some of the cupriferous pyritic deposits of Japan are found in younger formations. For example, those of the Hibira and Makimine mines in Kyushu are lenticular and bedded deposits, enclosed in phyllitic slates of the Paleozoic formation. They are similar in character to those found in the Sambagawa schists. They are clearly of epigenetic origin, having been formed by hydrothermal replacement and fissure-filling, as indicated by their occasional crossing of the bedding-plane, the occurrence of brecciated ores with the fragments of the country rock, and the widespread sericitization of the wall rock. They are genetically related to the so-called green phyllite, which is developed under-

neath the ore-bearing horizon and is nothing but dynamo-metamorphosed saussurite gabbro or diabase (allalinite phyllite), intruded into the slate complex as sheets. The intrusion of this basic rock and the ore-deposition have evidently been accomplished during a late stage of the orogenetic diastrophism in the latest Permian time, because the igneous rock has been subjected to intense dynamo-metamorphism, together with the surrounding slates and the ore deposits, whereas the post-Paleozoic rocks in that district show no traces of having been subjected to the same process.

3. The cupriferous pyritic deposits of the Hitachi mine, in Kwanto, afford another interesting type. They are similar in character to those found in the Sambagawa schists, already referred to, but they are more or less bedded masses, formed chiefly by replacement of the metamorphic rocks (amphibolites) of the Lower Paleozoic formation, evidently related genetically to intrusive granitic and dioritic rocks, the mineralizations ranging from contact-metamorphic to hydrothermal stages. The igneous intrusions are believed to be related to the Late Mesozoic orogenetic movements, and the metallization represents, clearly, the post-igneous actions belonging to a late stage of the long-continued diastrophic period. The metallic minerals replace and surround the constituents of the metamorphic rocks, including kinds of contact minerals, such as biotite, garnet, vesuvianite, cordierite and others, but the ore deposits show intricate contortion, in accordance with the wall-rocks, due to the schist-forming process.

In summary, most of the cupriferous pyritic deposits of Japan are of hydrothermal metasomatic origin, accompanied by more or less fissure-filling and impregnation, although they are of various geological ages and are related genetically to diverse igneous rocks, either basic or acidic. That they have a similar character, so that they may be designated by the general name of cupriferous pyritic deposit, is due, principally, to the fact that the country rocks have been subjected to similar dynamic processes, continuously, before and during, and even after, the formation

of the deposits. In other words, the metallization represents, in most cases, the latest phase of the igneous activity accompanying the great crustal movements, which have continued till after the ending of the formation of the ore deposits; ascension of the mineralizing solutions and replacement of the wall rocks having taken place, most pronouncedly, in the sheared or fissured zone along the schistosity formed by dynamic processes. None of the deposits in Japan can be explained as an injected sulphidic partial magma differentiated from the gabbroic magma.

TAKEO KATO.

DISCUSSION AND INFORMAL COMMUNICATIONS

KANSAS STATE AGRICULTURAL COLLEGE
JAN 22 1925
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ORIGIN OF CLINTON HEMATITE ORES.

Sir: Formerly there was considerable debate as to whether the Clinton ores were syngenetic or epigenetic but this phase of the problem of the origin of these ores seems now to be fairly well settled. The writer has compiled the opinions of thirty-four different writers on the origin of the Clinton ore. According to recent opinions, formed since these ores have been worked to depth, there have been few advocates of any epigenetic theory. The writer, after a field experience with Clinton ores dating from 1888 and covering mines in nine states, knows of no deposit of Clinton ore which, except for weathering alteration on the outcrop, he regards as anything else than an original sedimentary bed.

Stose now cites an occurrence of iron carbonate in the Clinton ore.[1] He is correct in his surmise that carbonate ore in the Clinton is not restricted to the Irondale deposits. It is probable that iron carbonate is not uncommon in the Clinton ore. Unweathered iron carbonate is so similar to limestone in color and in a variety of textures that it is readily mistaken for limestone. Iron carbonate in the Clinton ore may have been missed by miners many times. Certainly there is little record in the literature which indicates that it has been found by geologists. In 1858 Lesley said, "Old Slate Charcoal Furnace, in Bath county Kentucky . . . ran until 1838 upon Magnesian limestone ore in the Upper Silurian or Clinton Group."[2] It is not quite clear from this reference whether or not Lesley understood these ores to be carbonate,

[1] G. W. Stose, "Notes on the Origin of Clinton Hematite Ores," ECONOMIC GEOLOGY, vol. XIX., p. 405.

[2] J. P. Lesley, "Iron Manufacturers' Guide," p. 126.

but iron carbonate interbedded with the Clinton hematite occurs in commercial quantity in this region and the occurrence was mentioned by the writer in 1908.[3]

The Rose Run mine near Olympia showed a flat lying ore bed three to four feet thick composed largely of oölitic hematite but carrying some blue carbonate, part of which was oölitic. The carbonate had its strongest development at the top of the seam but occurred at different levels. Locally in the mine so much of the ore was carbonate that it was roasted before shipment.

The Old State furnace mine was reported to have had an average thickness of fifteen feet of shelly limonite underlain by three feet of iron carbonate. The limonite appears to have been originally carbonate and the entire deposit to have been composed wholly of carbonate. Carbonate which was in sight was composed largely of gray rounded oölites. Interspersed with the carbonate there were patches of red hematite composed of flattened oölites.

In the Horse Mountain occurrence of Clinton ore in Alleghany county, Virginia, there is a persistent bed of limonite several inches thick which caps the red hematite. This limonite is apparently an iron carbonate alteration. At other places in Virginia limonite in association with the Clinton hematite indicates carbonate occurrences.

The Cacapon sandstone which occurs through the Alleghany portion of Virginia is a formation with thicknesses of one hundred feet and more and composed largely of ferruginous sandstone carrying commonly ten to thirty per cent. hematite. Occasionally on the outcrop there are phases which are composed of porous limonite and at one point a four inch bed of iron carbonate has been found interbedded with the hematite sandstone. The limonite is apparently an iron carbonate alteration. Here there is a great formation three hundred miles long by twenty or more miles wide deposited under conditions which produced considerable quantities of ferric iron but which occasionally made

[3] ECONOMIC GEOLOGY, vol. 3, p. 759.

thin beds of ferrous iron. This formation lies immediately under the Clinton.

In both the Clinton hematite and the Cacapon red sandstone the presence of occasional beds of iron carbonate can be explained by the occasional deposition of organic matter along with the ferric iron.

The Newark formation in Pennsylvania, New Jersey and Connecticut is largely a red formation. In southern Virginia and in North Carolina the Newark carries coal. Here a geographical and possibly a time difference gave conditions favorable for vegetation in the southern Newark. It is equally probable that at intervals through the period of the formation of the Clinton ores vegetation flourished and provided a reducing and carbonating agent adequate to yield these carbonate ores.

R. J. HOLDEN.

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BLACKSBURG, VIRGINIA.

METHODS FOR HEAVY MINERAL INVESTIGATIONS.

Sir: In his timely and valuable paper on "Methods for Heavy Mineral Investigations" R. D. Reed[1] states:

> In regard to the very numerous separators that have been devised for use with bromoform, a good policy appears to be to use no one of them unless it is clearly necessary for the particular problem in hand.

I can agree with this statement so far as most separators are concerned. However, I have found an early form of the Spaeth sedimentation glass valuable for quantitative gravity separations of sedimentary minerals. This glass, apparently unknown to most petrographers, was described by Spaeth[2] in 1897 and is figured by Chamot.[3] Before the war it could be obtained from Germany at 6 marks. If specially made for mineralogical separations with heavy liquids the capacity might well be reduced to 20 cc., keeping the stopcock-well as large as possible.

[1] This journal, vol. XIX., p. 326, 1924.

[2] *Zeitschrift fuer angewandte Chemie*, 1897, pp. 10–11.

[3] "Elementary Chemical Microscopy," p. 165, 2d Ed., New York, 1921.

The Spaeth glass is most useful with small samples (one or two grams), which are adequate for most purposes if a simple mechanical separation has been made to eliminate all grains above ½ mm. or below 50 microns in diameter. In using the glass it is better not to remove the stopcock, but to obtain the heavy separate by turning the stopcock back to the vertical position and washing out with benzene from a wash bottle.

A. O. WOODFORD.

POMONA COLLEGE,
CLAREMONT, CALIF.

ORIGIN OF ASBESTOS VEINS.

Sir: In his interesting paper on "An Arizona Asbestos Deposit" in vol. XVIII., pp. 663–680, of this journal Professor A. M. Bateman considers that the Sierra Ancha chrysotile veins have, like the Canadian asbestos veins, grown at the expense of the vein walls which have receded because they were continually destroyed and not because they were pushed apart by growing fibers. The undisturbed character of the bedding in limestone, opposite 6½ inches of chrysotile in a 11 inch band of serpentine, is relied upon by Bateman to indicate the impossibility of the growth of the chrysotile veins by pushing apart its walls and to render it conclusive that the Sierra Ancha veins have to be explained by other means. It appears to me that another interpretation of the facts figured on p. 677 is possible.

Bateman shows (1) that the bands of serpentine are due to aqueous, magmatic solutions which contributed silica and magnesia to certain bands in the limestone and (2) that the development of the chrysotile veins within the serpentine is slightly later than the serpentine. In the development of the serpentine, volume changes may have occurred but they have not disturbed the uniform bedding of the limestone. The absence of these possible disturbances would appear to have been determined before the development of the chrysotile from the serpentine.

The material for the growth of chrysotile is the serpentine and a possible agency is the solution with which the serpentine is

saturated immediately after its development. The veins can then be pictured as a type of lateral secretion vein whose formation is not accompanied by any important addition of material to the serpentine. It is agreed that the crystal fibers have grown in the direction of their elongation and so it may be inferred that the source of supply for growth is provided substantially by the serpentine at right angles to the trend of the vein and in the direction of the cross fiber. As the molecular volumes of serpentine and chrysotile are probably identical, the transfer of the serpentine into the chrysotile vein, coincident with the growth of the vein and the widening of the vein walls, cannot be expected to disturb the bedding of the limestone. As much as is lost by the serpentine is gained by the chrysotile. It makes no difference whether a small amount of serpentine is transported into the chrysotile vein, with the production of thin veins, or whether a large amount is transferred, producing 6½ inches of chrysotile in 11 inches of serpentine. Much more might conceivably be transferred without either disproving the view that the vein walls are separated by the forces accompanying the growth of the fibers or establishing the view that the vein walls receded because they were eaten by the growing fiber.

In Taber's experimental case the material is supplied to the base of the growing fiber from external solutions through the pores of the vein wall and the growth and widening of the vein is described as mechanical and due to the force of crystallization. If the material supplied to the base of the growing fiber is derived from the wall rock and internal solutions, the picture of the process can be essentially the same.

On Bateman's view of replacement the source of supply for the growing fiber is limited to the plane of the vein wall. On the possible view of combined vein growth and replacement, the solution of the serpentine may take place at any point within its mass, at places most favorably supplied with solvent and at the most vulnerable part of any crystal but the fiber cannot grow until the solution has migrated to the vein walls.

FRANK H. STILLWELL.

UNIVERSITY OF MELBOURNE.

REVIEWS

Principles of Stratigraphy. By A. W. GRABAU. Second Edition. New York, A. G. Seiler, 1924.

This new edition of Grabau's well-known "Stratigraphy" is more properly a second printing. The book is not rewritten. It differs from the earlier edition in that typographical errors have been corrected. It is printed on thinner paper and is therefore an easier book to hold. Moreover, its price has been reduced to $5.00, and this is worth recording as a surprising novelty in these days of high costs of books.

W. S. BAYLEY.

The Geology of the Broken Hill District. By E. C. ANDREWS. Geological Survey of New South Wales. 4to, xix + 416 pp., 41 text figures, 124 plates. Sydney, Australia, 1922.

This Memoir, No. 8 of the Geological Series, includes the report of field work by Dr. Andrews and assistants, special petrographic studies by W. R. Browne and Dr. F. L. Stillwell, and chapters on mineralogy and industries related to mining by several contributors. In addition to the geologic data, chapters on the history of the district, the physiography, and the individual mines, smelters and manufactories make the book a veritable encyclopedia of mining and its connected activities in and around Broken Hill.

The district studied covers some four hundred square miles; the central portion consists of rugged hills of Archean rocks projecting through alluvial plains. The upfaulting of this mountain mass seems to have been periodic, as indicated by the stages shown on the Mundi Mundi fault scarp that forms the abrupt westerly face of this highland. The maximum relief is slightly less than a thousand feet.

The geologic history of the region began with synclinal sedimentation during Archean time, followed by deep burial of these sediments and the intrusion of numerous sheets and lenses; next came intense folding which, with the heat supplied by the intrusions, effected widespread recrystallization; great drag-folds and "zones of crush" resulted, providing channelways for the solutions that deposited ores at the close of this period of disturbance. Later, but still probably in the pre-Cambrian, these ore deposits were elevated, eroded, re-buried by sediments and glacial debris, depressed again and subjected to another more gentle fold-

ing with but slight metamorphism. In Cenozoic time another uplift occurred, with periodic faulting and accompanying erosion resulting in the present land forms.

The author has applied to this problem what appears to be an unusual capacity for classification and painstaking attention to detail. In fact, this is carried so far as to be bewildering to the reader trying to fix his ideas of Broken Hill by a reading of this memoir. For example, the sediments of the oldest or Willyama series are divided into seven varieties of schists, and these are discussed as to situations, types, associates, and relations under thirty-eight geographic heads; cross-references, which would be helpful, are altogether wanting, but this lack is partly offset by a comprehensive index. The igneous rocks are commensurately subdivided and classified, as are also the lodes,—which word, the author explains, is used in the Australian sense, denoting "a large ore deposit of irregular shape formed in the main by replacement." The two consulting petrologists, Mr. Browne and Dr. Stillwell, do not agree as to the igneous or sedimentary origin of the two rocks known locally as "Quartzite" and "Granulite." Each of these men has contributed a well-written appendix to the main work, detailing his arguments; these appendices, however, contain much valuable material other than the minor matter of failure to agree on these two rocks.

The chapters on structural geology and mining geology deal mainly with the region immediately adjacent to the great Broken Hill lode. The relation to the "footwall crush" of all the ore bodies, including those previously classed separately as of the hanging wall type, and the reasons that differentiate this lode from the Bendigo saddle-reef type with which it was first correlated, are explained and discussed. The lodes in the district are classified under ten mineralogic types, and discussed with characteristic detail under forty-one geographic subheads. Mineralogic relationships are presented as a preliminary to the section on the genesis of the ore deposits. These ores are ascribed unquestionably to a supposed igneous source, probably lying deeper than the present exposures.

The brief chapter on metamorphism outlines the changes produced by the intrusion of the "innumerable but disconnected lenses of pegmatite" and other rocks, and by the great pressures that produced the complex folding. The clay rocks and shales had developed in them coarse bladed sillimanite, and garnet in great abundance. There seems to have been a remarkable intrusion of small sills in great number prior to the folding of the rock mass.

The main structures in this district are described as broad folds on northerly axes, complicated by numerous local intricate folds. Faulting is a minor and later feature, but there is an extensive development of

drag flowage that gives the effect of strike faulting in the production of discontinuous linear elements with only slight offset. Where these dip steeply, they grade downward into folds, and are thought to have graded upward into overthrusts, now removed by erosion. Dragfolding is most evident in the weaker beds, the arrangement of which "suggests that the mass tended to glide over its base by puckering." The crush zones produced by this movement became the most permeable parts of the mass, and localized the flow of the ore bearing solutions; the places where local dragfolding adjacent to crush zones is most intense seem to have been most susceptible to replacement, and so these "puckerings, crinkles, and wallows" determined the location of the ore deposits.

In the chapter on Mining Geology the lodes of the district are classified and described. The main lode lies on a gentle curve over three miles in total length of outcrop; it is intimately connected with the "footwall crush" that forms the lower boundary of the ore deposit. The upper boundary is irregular, generally conforming to the crumpled structure of the hanging-wall rocks that it has replaced. The values occur in the "galena with zinc-blende pegmatite;" prominent accompanying minerals include green feldspar, rhodonite, garnet, and common gangue minerals. Details of this lode are illustrated by sketches, maps, and photographs. Other silver-lead lodes are described, and deposits of tin, tungsten and platinum, with some copper and gold occurring outside of Broken Hill proper.

The chapter on related industries contains short contributions by several men describing underground mining methods, flotation treatment of ores, smelting, electrolytic zinc production and steel manufacture, with descriptions of treatment methods, disposition, and a wealth of statistical data. In the following chapter, "Description of the Individual Mines" by E. J. Kenny, 24 properties on the Broken Hill lode and 51 elsewhere in the district are described separately.

The final chapter, on "The Future of Mining at Broken Hill," contains a discussion on "the methods available to the geologist when discussing the prospects of a mining district" that is well worth reading. This seems to be designed to convince mine operators of the value, as well as the limitations, of geologic work, but it contains a statement of principles that any young worker in geology may study with advantage.

The book throughout is characterized by a remarkable thoroughness of intimate description, but with details so profuse as to obscure the general perspective; or perhaps this very excellence in detail causes the somewhat inadequate summaries and generalities to suffer by contrast. Had the author applied to the statement of general principles a skill equal to that which he shows in the more detailed phases of his work, the book

would have been a masterpiece. As it is, it will take rank as an important contribution, and a valuable work of reference.

Covering the broad field that it does, the book is of disconcerting bulk, and this is aggravated by a style of makeup so conspicuously bad that it cannot be ignored. The margins throughout are inordinately wide. The book is lavishly illustrated with plates on stiff and heavy paper, many of which would be more effective as text illustrations. Little pictures, occupying only sixteen per cent. of the page space, swell the number of plates that keep getting in the reader's way; and all too frequently, when one is looking up an indexed item, the book opens repeatedly to the blank backs of two plates! These are little things, it is true, but the more annoying for their very pettiness; they leave an impression of fumbling and clumsiness that will surely result in the book being less widely read than it deserves.

Perhaps the author cannot be blamed for this, being bound by rules of bureaucratic uniformity. The reviewer estimates that the bulk and cost of the book could be reduced at least thirty per cent. by efficient arrangement; in the process, the ease of reading would be increased threefold. The book is priced at two guineas; too much of that cost represents wasted paper.

The maps accompanying the book show in some cases the same tendency to run into unnecessary size. The smaller maps and sections are useful, but the big ones are so big, both in size and scale, that they can find but little use except as wall maps.

The close student of Broken Hill will, in time, conclude that the author has accomplished a really fine piece of difficult and intricate work. It is unfortunate that the student whose interest in this region is merely casual and general should have his appreciation of the greatness of the work so obscured by the obtrusive bigness of the book.

STERLING B. TALMAGE.

HARVARD UNIVERSITY,
CAMBRIDGE, MASS.

SOCIETY OF ECONOMIC GEOLOGISTS

The first award of the Penrose Medal of the Society of Economic Geologists was made at the Council Meeting of December 12, the recipient being Prof. Thomas Chrowder Chamberlin of Chicago University. Formal presentation of the medal was made at the banquet of the Geological Society of America at Ithaca, N. Y., on December 30, 1924.

In concluding his presentation address, Pres. James F. Kemp of the Society of Economic Geologists stated:

"In summary, I may, therefore, select from the long series of contributions which Professor Chamberlin has made to our science the four which may be described, in accordance with the phraseology on the medal, as 'outstanding contributions to the earth sciences'—

1. The contribution on the lead and zinc veins of the Upper Mississippi Valley.
2. The contributions on the Ice Age.
3. The contributions on the Planetesimal Hypothesis and on the subjects which lie along the borderland between geology and astronomy.
4. The contributions on Diastrophism as a principle in the sub-division of geological time.

"Not alone for these, however, do we award the Penrose Medal. It is, also, an expression of the deep affection and respect with which Professor Chamberlin is universally regarded by geologists, at home and abroad."

The officers of the Society elected for the year 1925 are as follows:

President:	C. K. LEITH,
Vice-President:	A. C. SPENCER,
Councillors:	ADOLPH KNOPF,
	W. S. BAYLEY,
	CHESTER W. WASHBURNE.

At the recent ballot for members, the following were elected members of the Society.

George Carter Anderson,
Raymond Frank Baker,
Victor Brien,

Arthur F. Buddington,
Carl Bugge,
Alfred Granville Burrows,
William Egbert Cockfield,
William Myron Davy,
Emmanuel de Margerie,
Victor Dolmage,
Nicholas Wing Easton,
Harry von Eckermann,
Warren Homer Emens,
Victor Goldschmidt,
Arthur Lewis Hall,
Tsunenaka Iki,
Kinosuke Inouye,
William Alfred Johnston,
Bertram Reid Mackay,
Alexander Maclean,
Basil Prescott,
Robert Heron Rastall,
Howard S. Robinson,
Arthur William Rogers,
Edward Sampson,
Charles Henry Smyth, Jr.,
Felix Reinhold Tegengren,
William Taylar Thom, Jr.,
Henry Ward Turner,
Lennart von Post,
Robert Charles Wallace,
Leonard Keith Ward.

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SCIENTIFIC NOTES AND NEWS

S. R. Capps, of the U. S. Geological Survey, will serve as acting chief Alaskan geologist until April 1, 1925.

H. W. Turner has returned to San Francisco from an examination of mining property on the west coast of Mexico.

C. F. Tolman is on leave from Stanford University this quarter and is engaged in field work for an oil company in Santa Barbara County, California.

Philip D. Wilson, formerly chief geologist of the Calumet and Arizona Mining Company, is in Santiago, Chile, representing the American Metals Company.

Chester W. Washburne has sailed for Australia.

W. E. Wrather has again taken up his residence in Dallas.

G. F. Loughlin has completed his work at Cripple Creek, Colorado, for the U. S. Geological Survey. On December 9 Mr. Loughlin addressed the member of the Geological Society of the University of Cincinnati on "The Geology of Leadville, Colorado."

P. G. Beckett, formerly general manager of the Phelps Dodge Corporation, has been appointed to serve as vice-president of the corporation.

Frederick G. Clapp has been in Australia for several months, making geological explorations in the unknown regions of the so-called Kimberley desert.

James Gilluly and C. H. Dane, of the U. S. Geological Survey, have completed their field work near Thompson, Utah, and have returned to Washington.

R. M. Overbeck, formerly with the Shell Company of California, is at present serving as chief geologist for the Caracoles Tin Company at La Paz, Bolivia.

John A. Dresser, of Montreal, has made a complete examination and valuation of the Bingo gold mine in the Herb Lake area of northern Manitoba, as recent sampling failed to confirm the values previously reported.

Charles A. Mitke is in Mexico, examining the mines of the Cia. de Santa Gertrudis at Pachuca, Hidalgo.

Hoyt S. Gale has been directing geological investigations in California for the Gulf Corporation during the past year, with headquarters in Los Angeles.

D. R. Semmes sailed December 27 for Bombay, India, for a short petroleum reconnaissance, and will return about April 1.

Arthur Wade, the American geologist appointed by the Federal Government to investigate oil prospects in Australia, stated in his report to Parliament that he has been unable to find any possibilities of oil in payable quantities in the northwest of Australia or in the Northern Territory. He will next investigate certain regions in New South Wales and Queensland.

Ira B. Joralemon, consulting geologist of San Francisco, recently visited the Bisbee district.

James R. Evans has returned to New York from Angola and the Belgian Congo, where he has been engaged in professional work for several years.

Andrew Gibb Maitland, chief government geologist of Western Australia, has been awarded the Mueller memorial medal for eminent services in the cause of geology in that state and in Queensland and New Guinea.

A. E. Flynn, professor of mining at the Nova Scotia Technical College, is investigating the treatment of Nova Scotia oil shales for the Advisory Research Council, Ottawa.

John C. Anderson, consulting engineer for the Canario Copper Company, has been at Nacozari, Sonora, Mexico, studying the geology and planning further developments for the Canario Company.

The Winnipeg Board of Trade has established a Mining Bureau for the purpose of disseminating information regarding the mining possibilities of the Province.

The Southern Pacific Company has established an Industrial Minerals Service Bureau, under supervision of its Geological Department, for gathering data, testing minerals, and aiding in various ways the producers and manufacturers.

The thirty-seventh annual meeting of the Geological Society of America was held at Cornell University in Ithaca, New York, December 29–31. The meeting was well attended although, owing to the meeting of the American Association in Washington, there were fewer U. S. Geological Survey members present than usual. The physical facilities at Cornell proved unusually pleasing for the accomodation of the guests and for the holding of the technical sessions. Some 62 papers were listed for the first two days. In addition 16 papers were given before the Paleontological Society, the latter occupying the whole of the third day. Among the papers pertaining more particularly to economic geology were: the Presidential Address on Metasomatism, by Waldemar Lindgren; reports of Committees of Division of Geology and Geography of the National

Research Council, by David White, K. C. Heald, and W. H. Twenhofel; Basic dike injection in magmatic vein sequences, by J. E. Spurr; Discovery by geophysical methods of a new salt dome in the Gulf Coast, by E. DeGolyer; Genesis of calcite-barite-fluorite veins, by W. D. Johnson; Mineralization in Platteville-Decorah contact zone, by C. R. Stauffer; Modern study of Minerals, Presidential Address by H. S. Washington; Electrical conductivity of ore minerals, by P. F. Kerr and C. K. Cabeen.

The Washington Academy of Sciences held a meeting on January 13, when A. L. Day, Director of the Geophysical Laboratory, delivered an address on "The Study of Earth Movements in California." The following meeting on January 20 was a joint meeting with the Anthropological Society, the Archaeological Society and the Biological Society, and the program consisted of a symposium on "The Origin and Evolution of Man" with addresses by J. C. Merriam, A. Schultz, and A. Hrdlicka.

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